THE USE OF BOUYANCY TO LIFT HEAVY OBJECTS FROM THE SEA

Richard P. Fiske

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ABSTRACT

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Five systems are considered for use in the recovery process. Two systems currently used for installation are found suitable for modification to recover jackets. They are the pontoon barge system and the self-floating tower.

Major problems to be overcome in modifying for retraction are mating of the pontoon barge with the tower, developing a pile system which can be refurbished, and ensuring transverse stability on retraction through the air/sea interface.

THE USE OF BUOYANCY TO LIFT HEAVY OBJECTS FROM THE SEA

by

RICHARD PAUL FISKE
B.A., University of California, San Diego
(1969)

SUBMITTED IN PARTIAL FULFILLMENT
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Richard Paul Fiske

Submitted to the Department of Ocean Engineering on May 8, 1981 in partial fulfillment of the requirements for the degrees of Ocean Engineer and Master of Science in Naval Architecture and Marine Engineering.

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To recover oil from economically marginal offshore fields the re-use of production platforms has been considered. Re-use involves severing the jacket from the seabed, rotating the jacket to the horizontal and lifting it through the air/sea interface in a configuration suitable for towing.

Five systems are considered for use in the recovery process. Two systems currently used for installation are found suitable for modification to recover jackets. They are the pontoon barge system and the self-floating tower.

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Thesis Supervisor: Professor Chryssostomos Chryssostomidis
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CHAPTER 1

INTRODUCTION

1.1 Purpose

Since its inception in the late 1940's the offshore oil industry has been characterized by bold engineering innovation. The nature of both the environment and the economics of offshore oil drilling and production mandate innovative approaches to engineering problems.

With the depletion of world offshore oil reserves production of oil from fields holding marginal quantities of oil becomes economically feasible. As attention shifts to smaller fields fatigue life of the platform becomes less of a limiting factor and the question of relocation and re-use of a production jacket can be considered. The purpose of this thesis is to investigate the retrieval of an oil production jacket through the air-sea interface, including probable problem areas requiring further investigation and five potential jacket retrieval systems.

Aside from re-use there are a number of other reasons to remove a jacket or tower from its installed position once its active life is over. The platform is obviously a navigation hazard. It may be damaged, or it may be desired to sell the platform for scrap. Additionally, government regulations detail requirements for jacket removal.[1] Usually by the time

oil recovery in a field is no longer economical the platform's safe fatigue life has been reached and the platform itself is no longer usable. It is therefore less expensive to break the platform into pieces which can be lifted onto barges by an on-site crane than it is to develop a whole-jacket recovery system. The jacket pieces are then disposed of either ashore or in deep water. The scrap value of a typical jacket returns only 15¢ per dollar spent on retrieval.[2] In the re-use situation, however, the jacket must be economically recovered in a refurbishable and re-usable condition. If this can be accomplished, the savings in new jacket construction costs will be substantial, up to 50m for a 500 foot water depth jacket.[3] Thus, a new system of installation and recovery should be developed for re-usable jackets.

1.2 Recovery Problems

Myriad problems are evident when intact retrieval of a currently installed jacket is considered. The first question is the structural condition of the jacket. Fatigue may have reached the point where the stress of retrieval would cause catastrophic failure. There may be other structural damage, apparent or not, which could lead to a similar failure.

Second, existing jackets are thoroughly piled and grouted to the ocean floor. These piles must be cut below

the mud line with explosive charges or diver air arc. Either way the pile guides, which are frequently the jacket legs on smaller platforms, are practically unusable due to the grouted piles contained there-in. On the larger platforms the pile sleeves would have to be replaced, which not infrequently involves 8 piles per leg.

Third, after many years the watertight integrity of all structural members and tanks must be suspect. The flooding of structural members thought to be dry contributed to the recent failure of the attempt to right the Alexander Keilland in Norway.[4] An additional problem here is that almost without exception the tanks and voids of existing platforms were intended to be ballasted, but not de-ballasted. The valves have not been maintained and there are no piping provisions for deballasting. All this would have to be diver-installed and increased depth causes costs to increase dramatically.

In the case of barge-launched jackets there is only minimum provision for buoyancy anyway and frequently the formerly buoyant legs now contain grouted piles which, although they can be sealed, provide only minimal buoyancy. There is also the problem of ensuring that the jacket can be broken loose from the bottom and floated to a horizontal position at the air-sea interface for retrieval.

Fourth, an accurate weight estimate, particularly of a larger jacket, would be very difficult to make. It is

likely that accurate records have not been maintained, and anode and marine growth weights would have to be approximations.

Fifth, the topside structure and facilities would have to be removed.

Sixth, jackets usually have a pair of reinforced skid rails on one face, designed to support the jacket during construction, transport, and launch. These rails usually consist of "u" channel filled with wood (Figure 1.1). The wood and the rails and bolts that hold the wood in place are not usually maintained. This is the only area of the jacket, however, designed to support the jacket in a horizontal position. The rails must be diver-refurbished and since it is likely that no provision for re-use has been made, it will be a very difficult, time-consuming and expensive job.

Finally, and most significantly, the jacket must be recovered through the air-sea interface in a stable manner. It is this last topic which is addressed by this thesis.

1.3 Stability

From basic hydrostatics it is apparent that stability is a function of the positions of the center of gravity, center of buoyancy, submerged volume, waterplane area, and free surface. Upon arrival at the installation site a jacket rests on a rectangular barge or on a series of interconnected pontoons which act as a barge, or it is supported by the integral buoyancy of two or more of its legs. The system has a high

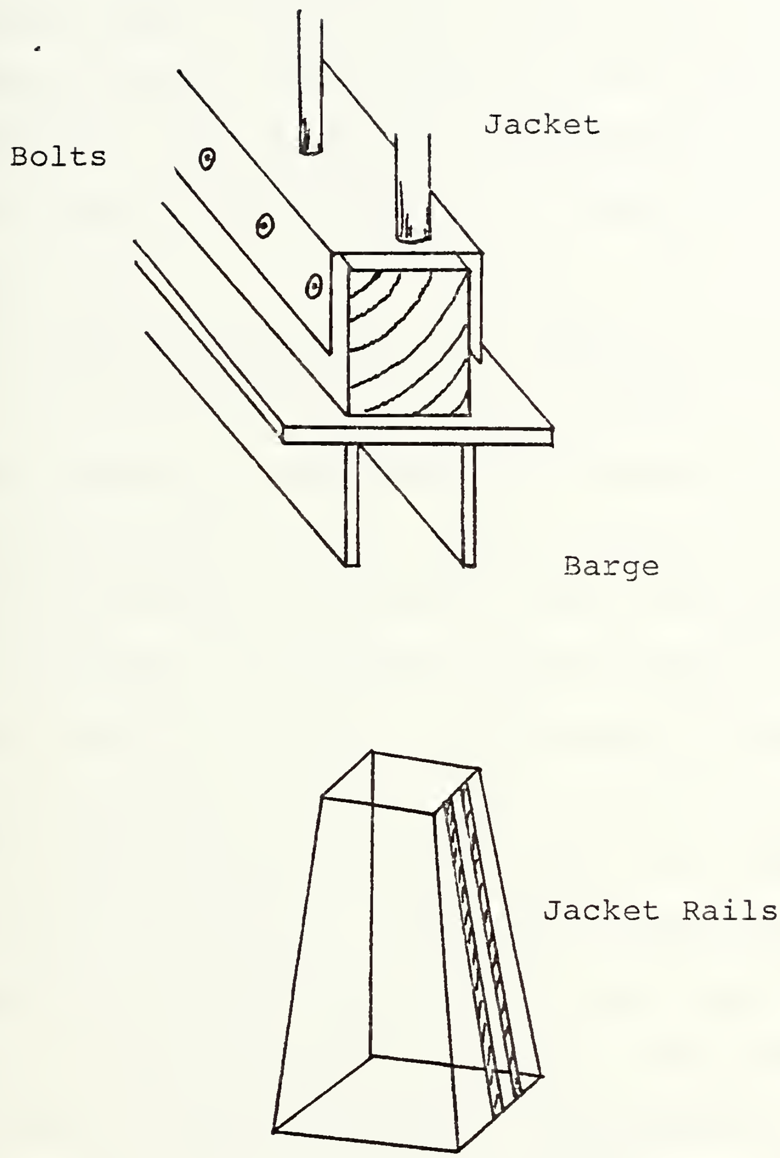


Figure 1.1 Jacket Skid Rail

center of gravity over a low center of buoyancy. The water-plane second moment of area is so large and its transverse and longitudinal righting moments are so great that both transverse and longitudinal GM are large positive numbers and the system is stable enough to withstand design weather and damage conditions.

To launch large jackets or towers at the installation site one of two launching/uprighting methods is used. In the first, the jacket is transported horizontally on a barge specifically designed for the purpose, (Figure 1.2). The restraining tie-downs are removed at the launching site, the barge is ballasted, and hydraulic jacks skid the jacket toward one end of the barge. As the weight distribution on the barge changes the jacket begins to slid on its own. At the end of the barge are a pair of large tilt beams aligned with the barge skid rails. The jacket crosses the tilt beams which rotate and support the jacket as the center of gravity passes aft of the tilt beam pivot point. The jacket slides into the water, coming to rest in a horizontal position with its upper legs at the air-sea interface. Once the jacket begins to move on its own this is a dynamic process and it takes only seconds to complete.

During the transition from barge to water the jacket is unstable in roll. The launch process begins from an even keel and is so fast, however, that upsetting moments have no time to operate on the jacket as the jacket quickly transits

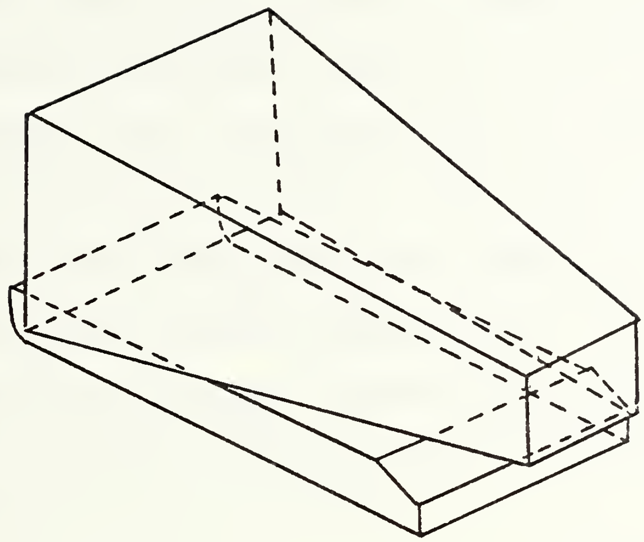


Figure 1.2 Jacket and Launch Barge

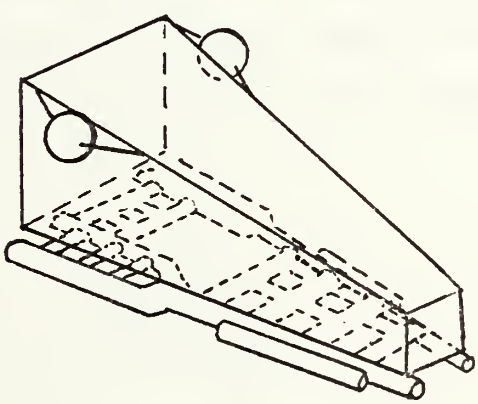


Figure 1.3 Pontoon Barge

this unstable region to a floating equilibrium position.

From its horizontal position in the water the jacket legs are flooded and, frequently with an assist from a crane lifting the top of the structure, the jacket is brought to the vertical, positioned over the landing site, and lowered through ballasting onto the ocean floor. Installation of stabilizing piles is begun immediately since the jacket is vulnerable to weather until it is securely attached to the seabed.

The second launch method involves a self-floating tower or a tower with a securely attached system of pontoons on its towing face (Figure 1.3). The pontoons are removed after the tower is upright on the seabed. At the launch site the tower is rotated upright and positioned using a sequence of stable equilibrium positions shown in Figure 1.4.

There are five stages in the upending and positioning process listed by Blight:[5]

1. Pre-Flood
2. Crash-Flood
3. Post-Flood
4. Trim-Vertical
5. Sit-On-Bottom

More recent authors term the Crash-Flood state the First Rotation.[6,7,8] With the exception of Crash-Flood the sequence of stages is one of continuous equilibrium.

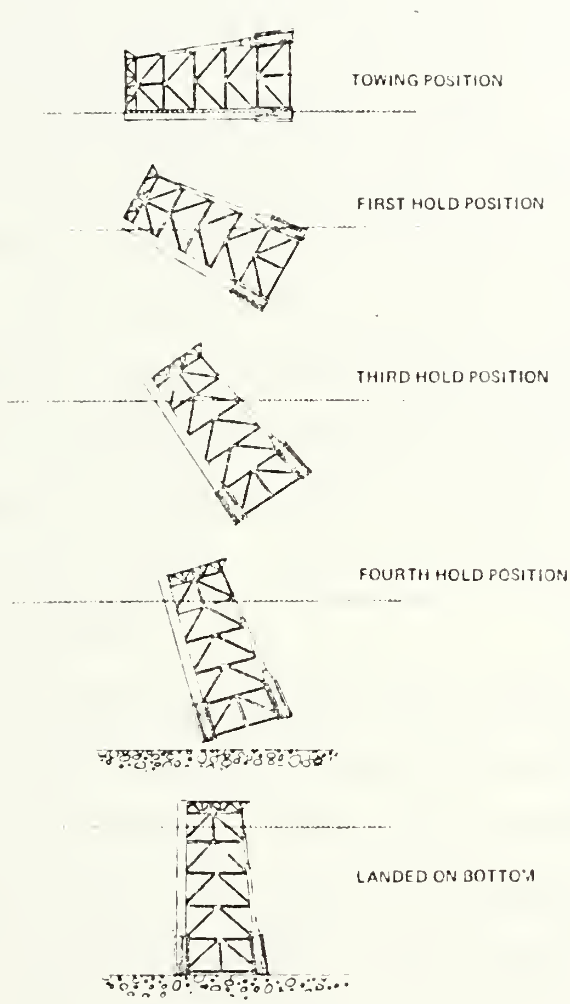


Figure 1.4 Self-Floating Tower Righting Sequence (taken from Ref. 6)

The pre-flood stage is a preparatory process. As the ballast tanks at the base of the platform are flooded, water plane is reduced, the center of gravity of the tower shifts toward the base and the center of buoyancy changes with the change in underwater shape and volume. The result is that longitudinal GM is rapidly reduced to zero.

At this pitch-critical point the crash-flood stage begins and a number of interesting things begin to happen, (Figure 1.5 and 1.6). First, the tower has become unstable in pitch and begins to trim toward the vertical. This rapid pitching motion is arrested by upper leg structures, using either larger diameter buoyant legs or large hollow spheres (Figure 1.4, first rotation). The tower is literally 'caught' and stabilized in pitch.

During the pitching process the tower has become unstable in roll since the transverse metacenter has shifted below the center of gravity. This can be corrected by rapid ballasting of the lower legs, which is accomplished by opening a number of large ballast valves as the crash-flood stage begins. Enough water is admitted over a period of 30-45 seconds that the transverse upsetting moments are unable to operate on the structure and it settles into the stable 'first rotation' position. Substantial quantities of theoretical, analytical, and experimental work are carried out to ensure

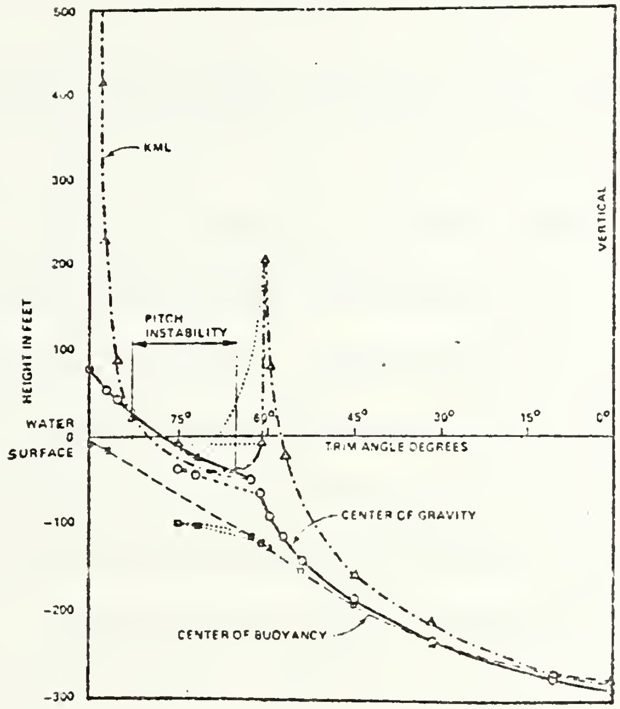


Figure 1.5 Stability Curves for Longitudinal GM (taken from Ref. 7)

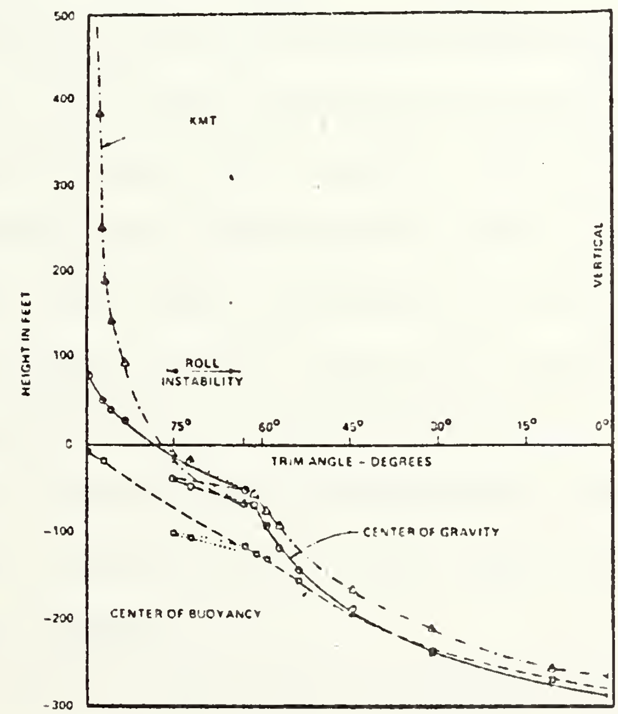


Figure 1.6 Stability Curves for Transverse GM (taken from Ref. 7)

that this re-stabilizing does in fact occur during the upending process.

Once the first rotation is completed, flooding of selected tanks continues until the tower is in a near-vertical position well off the bottom. This is also a critical point since buoyancy is provided primarily by the legs or pontoons on one side of the platform. The tower can pitch through the vertical into the pitch-inverted position, with the buoyant legs uppermost. Recovery from this situation is an involved process. This problem was avoided in the Ninian Field South Platform through the clever expedient of maintaining a pitch 19° from vertical while the tower was positioned over its final location. The tower flotation legs were then ballasted until the bases of those legs landed. As the legs flooded, the tower trimmed toward the vertical until contact with the bottom was made. The tower then began to trim toward the horizontal as flooding of the flotation legs continued. Thus, an accurate landing time could be determined. After landing was determined, flooding the flotation legs stopped and the upper legs were flooded to bring the tower to an upright position on the seabed.[6]

It is obvious that from a stability point of view installing a jacket or self-floating tower is a much easier process than retrieving one, primarily because of the dynamic

nature of the critical phases of the installation process. Retraction of a tower or jacket requires deballasting by either pumping out or by using compressed air. Large quantities of compressed air can be quickly drawn from storage banks but a substantial increase in structural strength of the lower legs would be required to withstand the over pressure of rapid deballasting. Machinery limitations preclude a 'crash-deballast' capability. Therefore, retraction of a jacket or specifically a tower must be a largely equilibrium process.

Roll stability must be maintained through the entire retraction process. Dynamics of rapid pitching or deballasting cannot be relied upon to quickly transit roll-unstable regions. During the reversal of the first rotation pitch stability in particular need not be maintained since as the self-floating tower is deballasted and pitch instability is initiated on retraction the tower will pitch down to a near-zero trim condition in a rapid, dynamic fashion, from which continued pumping can complete the transition to zero trim.

1.4 Potential Retrieval Methods

Initially, a number of candidate retrieval methods were investigated. In five instances it was possible that the system might work without major material or economic

problems or obviously impractical system configurations. Those systems received further consideration and a chapter of this thesis is devoted to each one.

The first of the five final systems is termed Side-Barge Stabilization (Figure 1.7). The primary buoyant force is provided by a large submersible barge. The barge is ballasted until it is slightly negatively buoyant. The submerged barge is positioned and supported by cables leading to winches on two or more side or stabilization barges. The floating jacket is positioned over the barge, the barge and jacket are mated, and the barge is deballasted. The side-barges provide stability until the barge and jacket surface and the waterplane of the barge can raise the metacenter high enough for GM to become positive. Continued deballasting increases the freeboard, reserve buoyancy, and positive GM.

The second system consists of the same barge and jacket, but in this instance stability is provided by four vertical pontoons which are ballasted to neutral buoyancy and joined to the jacket while it is submerged (Figure 1.8). Side barges would be required only for the approach and mating portions of the retraction sequence. The clamp-on pontoons provide roll stability in the form of buoyancy and waterplane area as the barge is deballasted and the jacket is raised through the interface.

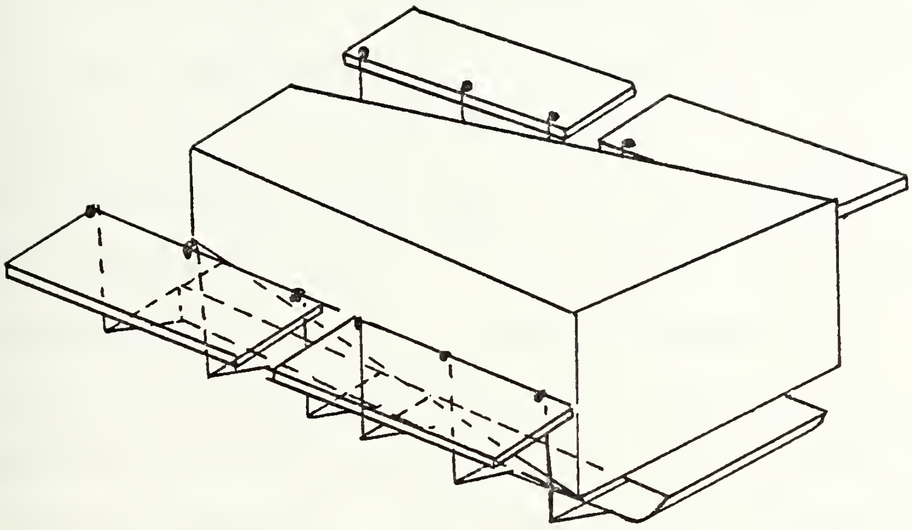


Figure 1.7 Side Barge System

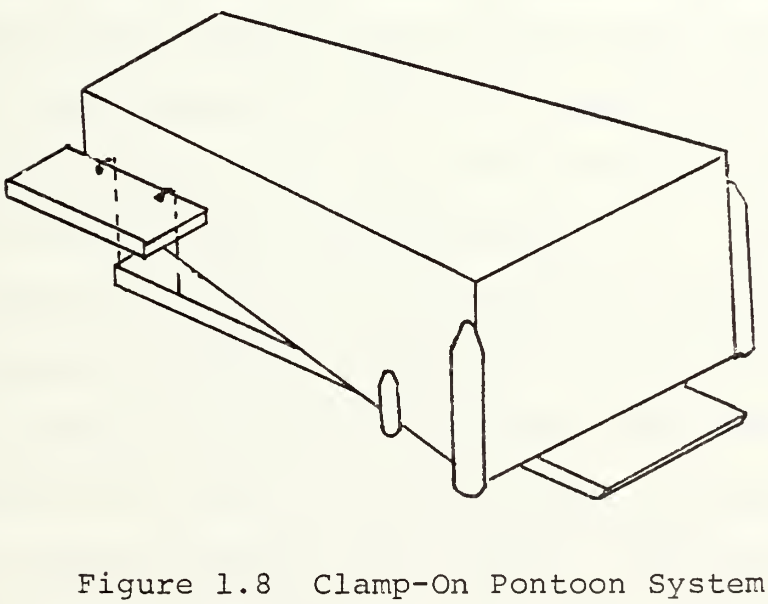


Figure 1.8 Clamp-On Pontoon System

In the "Stable Barge" system (Figure 1.9), roll stability is provided by superstructures mounted on the barge itself. These superstructures are trapazoidal in plan view and provide a pair of stable wing walls in the same manner as a floating drydock, but these walls are shaped to accommodate the tapering structure of the jacket. As before, side barges are required for depth and positioning control of the lower end of the barge. The superstructures are located at the upper end of the barge and do not submerge completely, thus providing excellent line-handling and jacket positioning platforms. Damage control will be a major consideration since a similar vessel, the Wijsmuller "Super Servant" was sunk in March of this year when one of the stability towers was holed while transferring a jack-up rig off the coast of Nigeria.

The next retrieval method is a modification of the pontoon barge system used in the installation of two sets of two North Forties Field jackets (Figure 1.10). The rectangular barge is replaced by a series of interconnected pontoons. In the installation phase the jacket is mounted on the barge, which is floodable in discrete sections. The barge remains attached until the jacket is on the seabed whereupon it is flooded to neutral buoyancy and removed. Additional stability tanks are attached to the upper tower legs. Stability for retraction is accomplished through modification of the pontoon barge or selectively enlarging certain jacket braces.

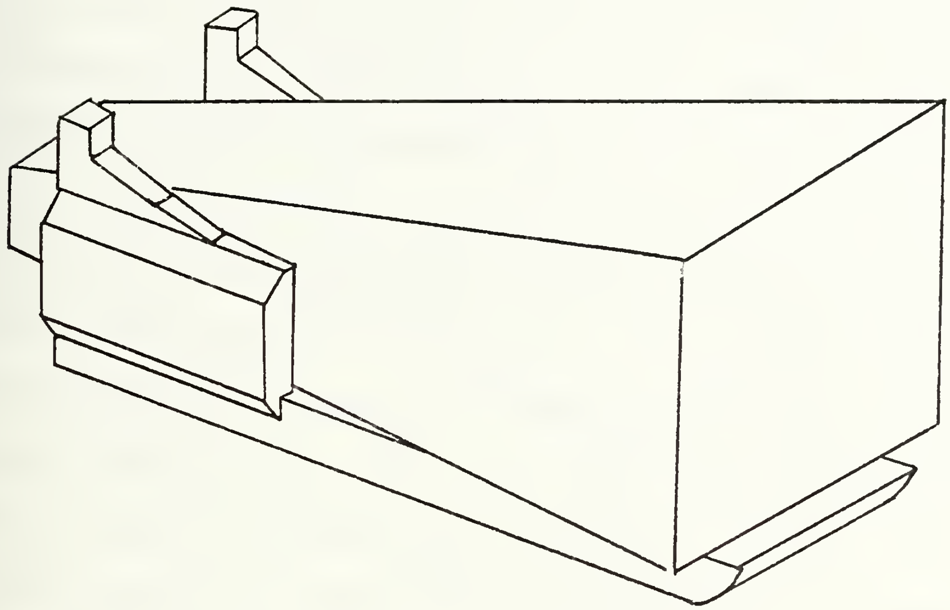


Figure 1.9 Stable Barge

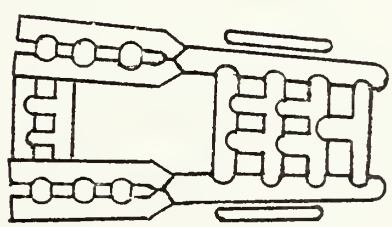


Figure 1.10 Pontoon Barge

The final retrieval method is a variation of the self-flooding tower concept, of which the Ninian Field South Platform is taken as an example (Figure 1.11). Two of the legs are oversize to provide flotation for the tower structure while it is being towed to the installation site. The legs are sufficiently large and compartmented in such a fashion as to provide adequate intact and damage stability and reserve bouyancy for the environmental conditions expected during towing and installation. The upper legs have enlarged bases to provide stability during the uprighting process. For retraction additional transverse stability will be required.

Several other alternative retraction and stability systems were investigated, but in considering them for large (20-25,000 ton) jackets most had major deficiencies which were immediately apparent.

The simplest retrieval method is to use a heavy lift craft to bodily lift the jacket from the water and place it on a waiting barge. This is a preferred launch method for small jackets, but as of November 1980 the largest capacity lift craft was capable of lifting 3000 tons. Only 3 of those craft exist and only another 13 are capable of a 2000 ton lift.[9] Thus, a straight lift of 25,000 tons in not a realistic possibility.

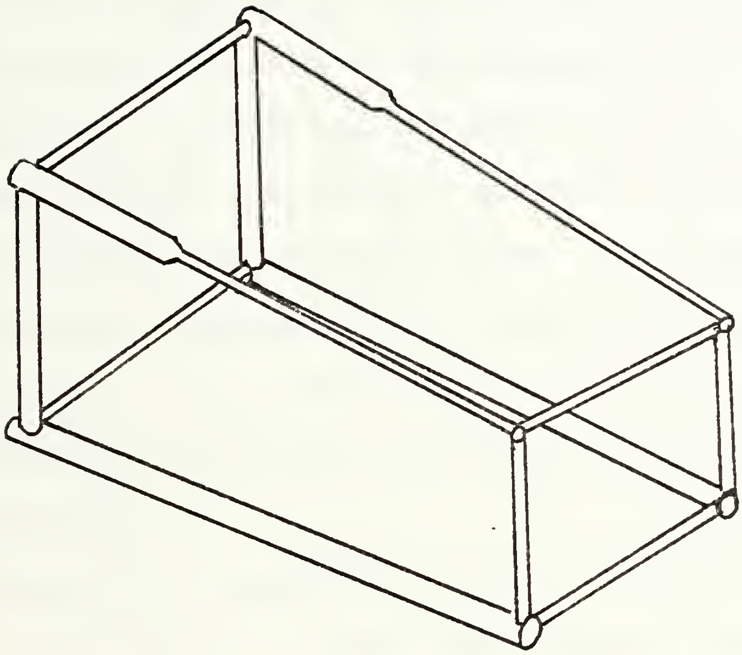


Figure 1.11 Self Floating Tower

A second method is to tow an almost completely submerged, slightly positively buoyant jacket without lifting it through the air/sea interface. The submerged tow is the easiest method for transfer to a nearby reinstallation site, but for long distance the towing resistance would be high and the tow speed correspondingly slow. This method has been used to tow a damaged 500 ton jacket to deep water for disposal, however, the jacket piles had not yet been driven.[2] Also, a submerged tow permits only diver-accomplished refurbishment of the jacket.

A case can be made for towing the jacket to shallow, sheltered water where it is positioned over a sunken barge which is then deballasted. However, the deepest point of the 25,000 ton nominal jacket used for calculations was over 180 ft when floating horizontally. And that still leaves unresolved the problem of transverse stability as the barge is deballasted.

Another possibility is to use inflatable lifting balloons. Currently, the largest balloons are in the 25 tonne range with a diameter of 3.5 m. However, as the lower side of the jacket approaches the interface, whether the jacket is supported by a barge or the balloons, the required righting moment for a 3° list, discounting any dynamic effects, is roughly 2.32×10^5 foot-tons. This would require roughly 42 balloons per side per row clustered toward the large end

and less than 10 ft vertical spacing between each row of balloons for a total of over 400 balloons per side. This level of effort is an outside possibility for a single retrieval or salvage operation, much more investigation would be required to justify a lift-balloon stability system for jacket retrieval on a routine basis.

The use of four or more steadying barges of the type proposed by the Navy Civil Engineering Laboratory at Port Hueneme, California, for heavy weather lifting is a possibility.[10] These large buoys would be positioned above the four corners of the submersible barge and would fairlead lift wires through vertically pivoted stand-off braces to an adjacent winch-equipped barge or work boat (Figure 1.12). One end of the barge would require a substantial (fifty foot) transverse extension structure to clear the jacket. The buoys would provide righting moment as the lift barge rolled. To provide a 2.32×10^5 ft-ton righting moment, at 3° roll 4 buoys of roughly 33 ft radius each would be required. In addition to these large buoys the required righting moment, particularly for larger rolls, greatly increases the required number of support wires. The wires must also be tensioned enough to submerge half the buoy in the level-barge condition. Any roll imposes an additional load on the low side. Use of the buoy steading system in this application cannot be completely

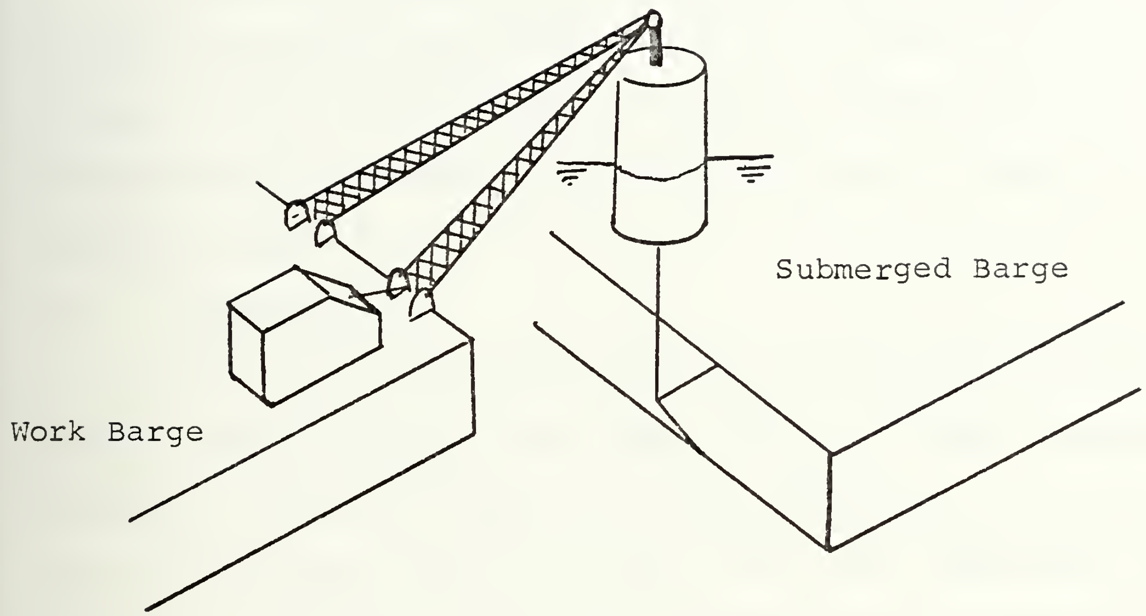


Figure 1.12 NCEL Stable Lift Buoy

discounted from a technical standpoint, but much further investigation is required.

Stability imposed by a weight stiffly suspended below the lift barge was considered briefly. To lower KG by the required 45 feet would require a 20,000 ton weight stiffly suspended 260 feet below the keel of the barge. This is not considered practical.

1.5 Assumptions

Due to the preliminary nature of this investigation certain assumptions have been made. Some of these assumptions are easily verified, others will require substantial analytical and/or experimental work to verify, and still others may turn out to be invalid or economically unfeasible to implement. In any event, list of major assumptions has been compiled here.

In the ship design realm of naval architecture new design concepts are frequently brought forth as variations of well established designs or techniques. This evolutionary process establishes a commonly agreed-upon baseline and, with the understanding that the impact of the modification on the entire system must be assessed, attention can be focused on the modification. That philosophy has been followed here. Thus, intact and damage stability considerations, towing resistance, and structural stability criteria are assumed to be satisfied initially. Impact on these factors by individual variations will be noted, if not addressed in detail.

The baseline jacket barge combination for the first three cases is taken to be the combination used by Sekita, Sawada and Kimura in their paper 'Model Tests on the Transportation of a Large Offshore Structure by Launching Barge'[11] (Table 1.1). The barge used in this study has dimensions similar to the Brown and Root barge BAR 376. A number of other authors address the characteristics of very similar combinations. The barge and jacket are both relatively large structures and it was thought that if a retraction system could be outlined for this combination retraction of smaller jackets would be a matter of scaling down from a known datum.

In the self-floating tower case the Ninian Field South Platform is the baseline. Its basic characteristics are shown in Table 1.2. Again, substantial work has been devoted to the Ninian South Tower, and the retraction system involved here uses a variation on the tower.[6,7,8]

In the final case, in which flotation is provided by a pontoon barge, the baseline system is the North Sea Forties Field platforms FA and FC discussed by Blight[5] (Table 1.3).

The next major assumption is that the BAR 376 design can be adapted to make the barge submersible. This is not as major an alteration as it initially appears. First, the machinery spaces and associated cooling, fuel, and lubricating spaces would have to be made hard, i.e. able to withstand water pressure to roughly 200 ft. The barge's ballast tanks

	Barge	Barge & Jacket
Diaplacement	15000 tons	21.3 ft
Draft	7.2 ft	19.7 ft
ΦG	19.7 ft	66 ft
KG	22.3 ft	55.4 ft
GM		
Length	580	
Breadth	160	
Depth	37	
	Jacket	
Length	623 ft	
B x D (Base)	289 x 187 ft	
B x D (Top)	138 x 66 ft	
Weight	25000 tons	

Table 1.1 Nominal Barge and Jacket
(Taken From Ref. 11)

Overall Height	523 ft
B x D (Base)	246 ft x 246 ft
B x D (Truss Level)	180 ft x 180 ft
Flotation Legs	30.2 ft Constant Diameter
Upper Legs	5.9 ft to 30.2 ft diameter
Weight	18000 tonnes

Table 1.2 Ninian Field South Platform
(Taken From Ref. 8)

Overall Height	410 ft
B x D (Base)	227 ft x 227 ft
B x D (Truss Level)	118 ft x 118 ft
Pontoon Barge	30 ft dia flotation pontoons, 20 ft sponsons
Upper Leg Pitch Stability	51 ft diameter spheres
Weight	27360 LT

Table 1.3 North Forties Field FA Platform
(Taken From Ref. 5)

would require a manifold for distribution of surface supplied air for deballasting. These tanks could remain at slightly above ambient pressure. The deballast air could be supplied to the top of the tank. A separate open vertical pipe would extend from one open end in a tank sump or low corner through the top of the tank. As air is supplied to the tank, water is forced out through the vertical pipe. The water level lowers until the bottom of the pipe is exposed whereupon excess air is vented out the pipe. The pipe should be located at the lower, outboard corner of the tank, so if the barge rolls as tanks are being deballasted in pairs the upper tank will vent while the lower, heavy tank is still being deballasted. Depth control is maintained by wires on the outboard corners which are tended from barges on the surface.

Barge tanks are symmetrically oriented and small enough so that they can be deballasted evenly and in tandem, and with minimum free surface effects. Air will be supplied from the surface through umbilicals. Calculations will require a specification for internal overpressure. The author is developing a deballast valve which will permit a preset tank overpressure, independent of supply overpressure. By allowing pressure on either side of a sliding dump valve to open or close the valve, desired overpressure is established with a bias spring.

It is assumed that installed valves and piping can be used and necessary new fittings will be added to existing platforms. It is further assumed that the required survivable deballast capability can be designed into future platforms and that this capability will be usable after many years in place underwater.

The jacket or tower is assumed to still be structurally sound and the skid rails are assumed to be refurbished, or on newly designed towers a minimum maintenance skid system has been incorporated into the design. In the pontoon barge case it is assumed that the pontoon attachment points are still structurally sound and usable.

The next significant assumption in the first three cases is that the jacket has been freed from the bottom and is floating intact in a horizontal position at the surface. Detaching the jacket from the bottom is not a major undertaking, however, the costs and equipment required to float the structure to the surface, intact, in combination with the costs of the retraction system from the floating position through the interface may exclude the first three cases from further consideration

In the last two examples, the self-floating tower and the pontoon barge, it is assumed that the tower is broken loose from the bottom, with piles cut and perhaps with the

aid of perforated hoses installed in the tower bases to break suction with the bottom. In any event, the tower is being held down only by ground reaction.

Finally, the modelling of stability during the transition process is of a primitive and static equilibrium nature. When the dust of the initial investigations settled it became obvious that more sophisticated, dynamic models will be required to adequately describe the retraction sequence.

CHAPTER 2

SIDE BARGE LIFT SYSTEM

2.1 Basic Concept

It will be recalled from the introduction that the side barge system uses the righting moment provided by two or more side or steadying barge to maintain the transverse stability of a submersible barge as the barge surfaces with its 25,000 ton deck cargo. This chapter will investigate the barge deck-load distribution and longitudinal shear and bending moment requirements, intact and damage stability criteria for the surfaced barge and the requirements inherent in three phases of retraction: preparation, mating, and lifting.

2.2 Structural Verification

The first step in structural verification is to determine a load distribution for the jacket on the barge. The jacket is longer and wider than the barge, overhanging the stern and both sides. Because the jacket's center of gravity is only about one third of the jacket length from the base, the base of the jacket does not overhang the bow and in fact ballast is required aft to maintain near-zero trim.

The jacket was modeled as a pyramid to find both the center of gravity and the skid rail load distribution. The

jacket weight was concentrated at the seven jacket elevations. The seventh or uppermost elevation did not bear on the barge and its weight was redistributed. The jacket was then positioned on the barge so as to minimize stern overhang, leave room forward for skidding jacks, minimize ballast required for zero trim and permit level 6 to bear on the barge (Figure 2.1). The required ballast was 9526 LT. The resulting hand calculated still water barge load, shear, and bending moment diagrams are shown in Figure 2.2. Table 2.1 shows the results of hand calculations and MIT's 'MIDSHIP' program. Distances are from the bow and displacement is 49477 tons. The still water correlation between MIDSHIP and hand calculations is only fair, but both are well within the ABS guidelines. The sagging bending moment is likewise satisfactory. The hogging bending moment exceeds ABS guildlines. However, the calculation for ABS is based on a 21.98 ft wave vice the 26.49 ft wave calculated by MIDSHIP. Also, shifting the 9526 tons of ballast forward will help reduce trim and minimize hogging BM. The MIDSHIP still Water trim of 2.77 ft would be eliminated by shifting the ballast 86 ft forward.

Local structural strengthening has been added to the barge to support a 25,000 ton jacket during transport and launch sequences.

	Max Shear Tons	Location ft	Max BM ft-tons	Location ft	ABS BM/Wave HT	LCG	Trim	Wave HT
Still Water Hand	-4097	150	149928	470		290	0	0
Still Water Midship	-3060	406	1950918	290	536791/	289	2.77	0
Hogging Midship	7622	232	-113951	348	94491/21.98	289	.48	26.49
Sagging Midship	-6688	174	-731004	348	816605/21.98	289	3.1	26.49

Table 2.1 Shear, Bending Moment, and Trim From Hand Calculations and MIDSHIP

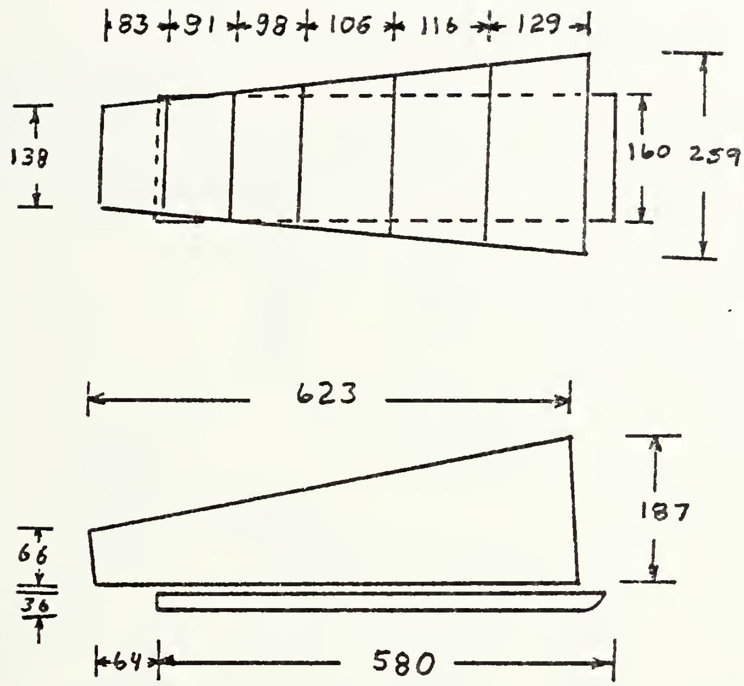


Figure 2.1 Nominal Jacket and Barge

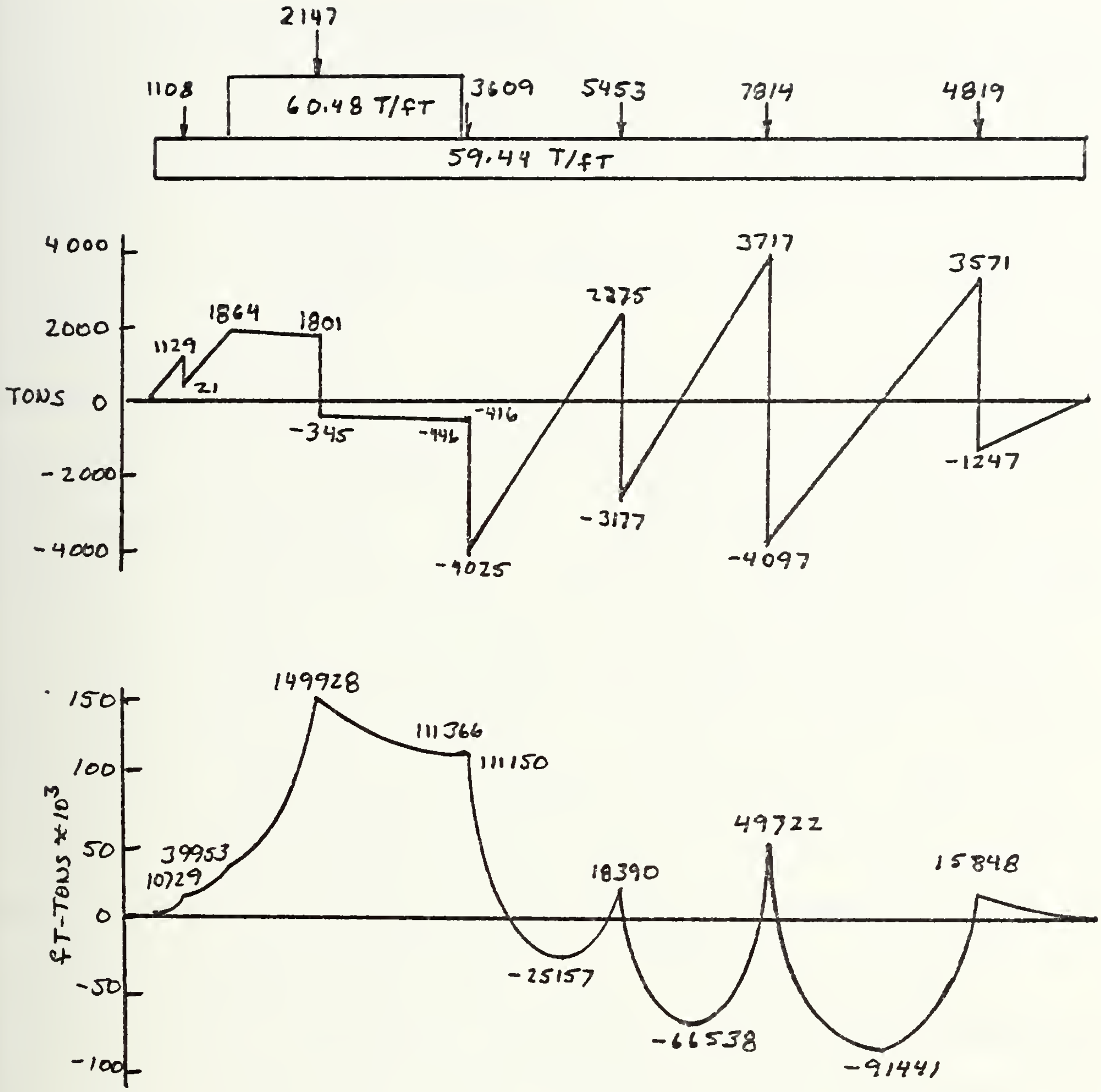


Figure 2.2 Load, Shear, and Bending Moment Diagram

2.3 Environmental Loading

From ABS guidance on mobile offshore drilling units the wind imposed rolling moment is

$$M = \frac{.0038 V_k^{\,2}}{2240} [C_{hB}\ C_{sB}\ A_B\ H_B + C_{hJ}\ C_{sJ}\ A_J\ H_J]$$

where V_k is the design wind velocity C_{si} are shape factors for the barge and jacket, C_{hi} are height coefficients and h_i are centroid heights.[12] For a 100 KT wind the moment, at 0° roll, is 54,550 ft-tons. Similarly, the pitching moment is 37,855 ft-tons. The jacket was assumed to be on 3 ft high rails and barge freeboard is assumed to be a conservative 20 ft. These results agree with Sekita[11] with the exception of his inexplicable use of 1.2 for his C_h vice 1.0 as used in ABS. The remainder of Sekita's model testing and computer analysis confirmed that if care was taken in ballasting and tie-downs a similar jacket barge combination was stable during the transit phase for both wind and wave loading. Jacket tie-downs are in particular are sensitive to wave loading because of the large dynamic forces generated by wave action.

Szajnberg[13] points out that the principle intact stability criterion used by most agencies is the area ratio criterion. This states that there must be a minimum of

40 percent reserve righting arm area over wind heeling arm area to the lesser of either the downflooding or second intercept angle (Figure 2.3). From only the roughest approximation it is obvious that this criterion has been met.

2.4 Preparation

The number of side barges used is an early design decision, since that will have a major impact on the remainder of the design. It was felt, since this is relatively unexplored territory, that four was the minimum number of side barges of nominal 250 ft length that could accomplish the task at hand.

Since the jacket overhangs the barge by nearly 50 ft on each side at the jacket base end (bow), a significant problem has already developed. Whatever righting moment is later determined to be necessary will have at least one righting arm in the 130 ft range. However, the price of this very helpful lever arm is a fifty foot extension on each side of the barge, and the lever arm structure must be capable of both withstanding a vertical pull of several thousands tons and not impeding navigation. One possibility is to shift the lift point aft on the barge, but even 100 ft from the bow a 42 ft extension is required. Another possibility is a folding boat boom type of arrangement

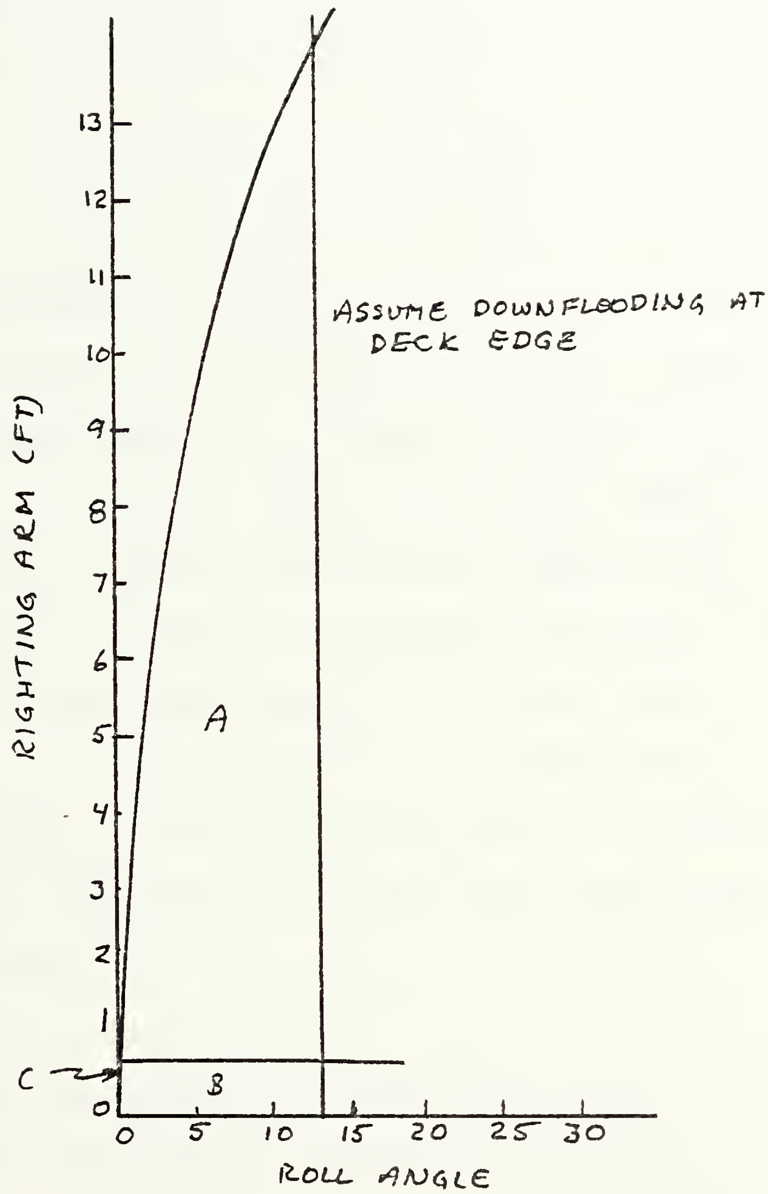


Figure 2.3 Wind Stability Criteria

using a horizontal upper member and a diagonal tension member or cables. For a 3000 ton lift the diagonal tension force, given that the 36 ft barge depth is used, is 5,230 tons and solid cylindrical brace 22.3 inches in diameter is required. For simplicity here it is assumed that all 12 righting arms are 130 ft.

Prior to receiving the jacket the side barges are positioned in 6-point moors and the barge is submerged at an angle corresponding to the 11° slope of the lower face of the jacket. With its upper end at about 80 ft submergence the barge is ballasted in a slightly negative condition, heavy enough to keep the cables taut in any current that may exist, but not heavy enough to put undue strain on the side barge system. Barge positioning lines could extend from the lift barge diagonally in a vertical plane to be tended from the outboard sides of the side barges.

The jacket, floating horizontally, is maneuvered over the barge using work boats and lines from the jacket to the side barges.

2.5 Mating

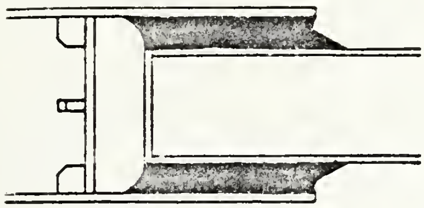
Mating the jacket and barge is a sensitive operation because of the large masses and close tolerances involved. The design impact criterion was a 1 ft relative heave in 15 seconds, which meant a maximum heave speed of .419 ft/sec

and a maximum impact energy of 68.15 ft tons for a one point impact of the 25,000 ton jacket.

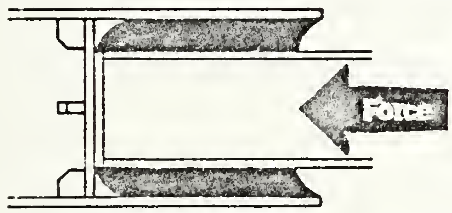
The first problem was one of guiding the jacket into the proper landing position over the barge. The second was cushioning its landing onto the launch rails as the barge is hoisted up to the mate with the jacket. Stiff structural members would either damage themselves or the jacket.

Shock-absorbing guides would work, and a commercially available solution to both positioning and landing problems was found in the Regal Marine Products fendering system.[14] The concept underlying Regal's many variations is shown in Figure 2.4. Two short concentric cylinders one joined by a rubber annulus. As one cylinder is displaced axially with respect to the other energy is gradually absorbed. Energy can also be absorbed by lateral deflection. Capacities and deflection curves for various shock cells are given in Appendix A. A pair of shock cells can also be joined with a third transverse energy absorbing device. This "Defender" system is commonly used for boat fendering in the offshore industry. These shock cells have also been used in platform legs to cushion the landing of platform superstructure. The model SC2036 can absorb 77.9 ft tons in a 12 inch stroke, matching the impact energy criteria.

It is now possible to use this system for both fine positioning and touchdown. As the base is raised to mate with



Shock cell cross section with no load applied.



Energy is dissipated in the loaded shock cell by subjecting rubber to shear.

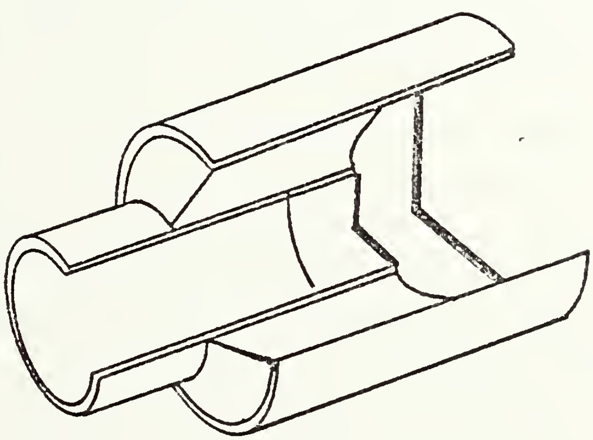


Figure 2.4 Regal Shock Cell

the jacket guides such as the ones shown in Figure 2.5 can nudge the jacket into final position and another group positioned transversely on the skid rails can absorb landing impact. The absorbed landing energy would, of course, have to be released prior to skidding the jacket ashore for refurbishment. This could be accomplished by positioning the shock cells on extended mechanical or hydraulic jacks prior to mating.

A hydraulic cushioning system was considered, but the complexities of a hydraulic system at 100-200 ft submergence were not thought to be worth the effort with the simple and tough shock cell system available.

After the jacket is positioned and the barge raised to mate the two, a temporary clamping or restraining system must be present to hold the jacket in position until the barge surfaces and transit tiedowns can be welded in place. Transverse and longitudinal motion can be eliminated with the vertical guides shown in Figure 2.5. Vertical motion, while not anticipated during the lift may occur due to dynamic rolling effects. It is therefore necessary to provide a vertical restraint. The simplest latching mechanism would be a cross-piece driven down and latched by hydraulic pressure generated by the action of the jacket settling onto the barge (Figure 2.6). A slight complication here is that the latch

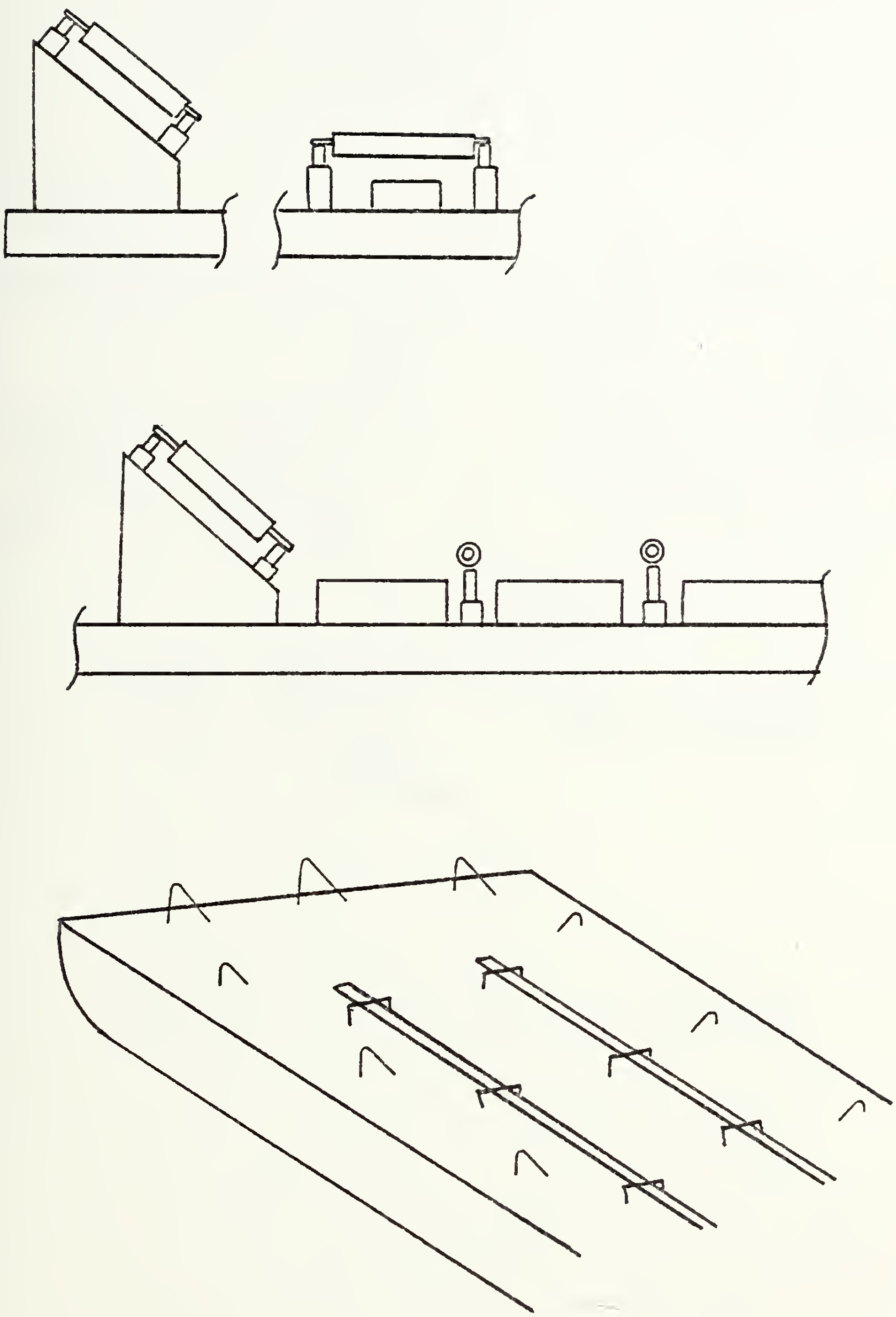


Figure 2.5 Jacket Positioning and Fendering System

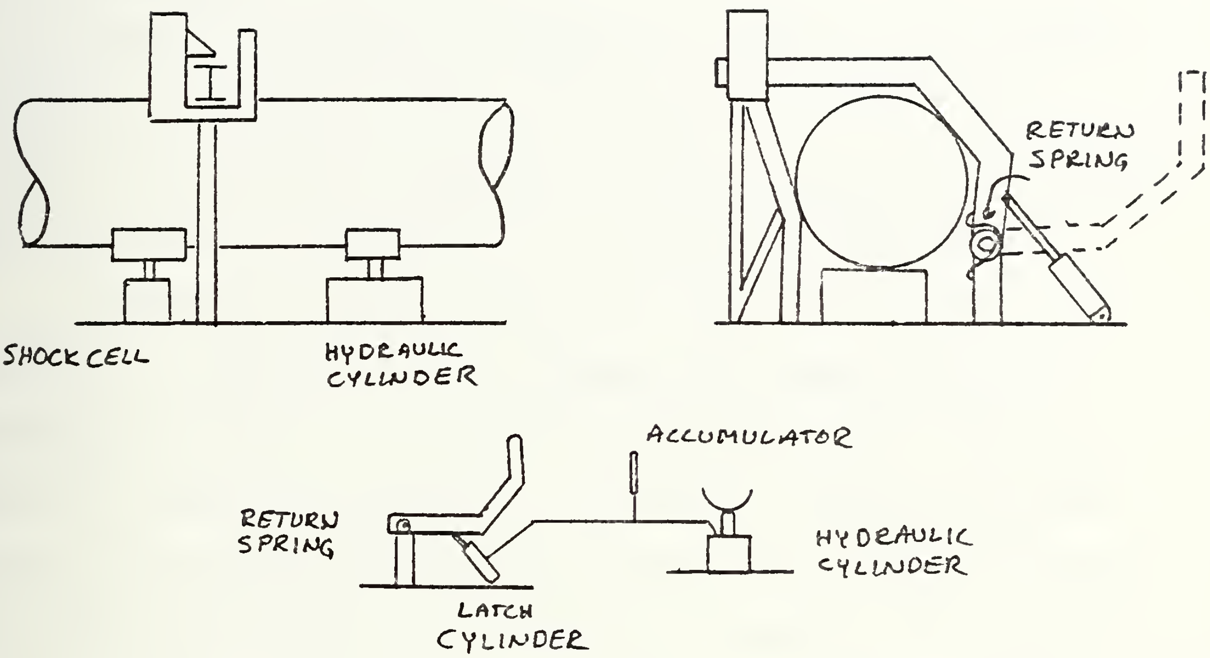


Figure 2.6 Jacket Latching Mechanism

arm must be protected until the jacket is nearly landed. A return spring keeps the unforced system open unless it is latched. The jacket is now in position and mated to the barge.

2.6 Lifting

Before the lifting process can begin it is necessary to develop a static stability model of the jacket barge system. Then required righting moments and arms can be found and the structural and machinery requirements determined.

The most unstable position in the lift is near its completion. Except for trim ballast and enough water to submerge the barge it has been nearly pumped dry, thus the center of gravity has risen to the weight averaged midpoint of the line joining the centers of gravity of the jacket and the deballasted barge. The jacket is assumed to be a point load at its center of gravity. Simultaneously, since the jacket is nearly clear of the water, the center of buoyancy has dropped to the midpoint of the barge. Finally, if the barge is assumed to surface with near zero trim then there is no waterplane to provide transverse stability. Thus, from Figure 2.7 it can be seen that at this least stable point in the lift GM is - 47 ft, and from that an upsetting moment vs. roll angle plot can be drawn (Figure 2.8). Keeping in mind that the submerged barge provides the primary buoyant force, the addition of 1,000 tons of buoyancy from each of the 4

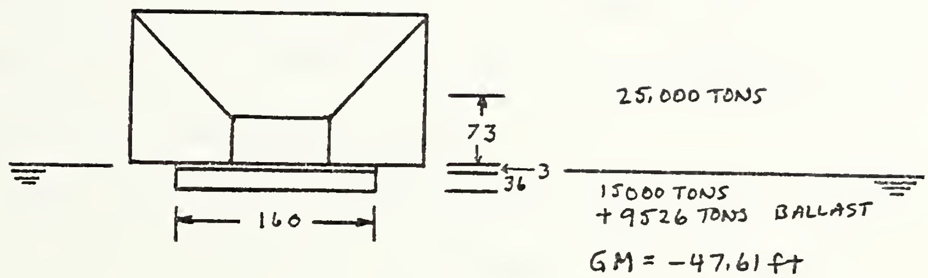


Figure 2.7 GM of Jacket Barge Combination

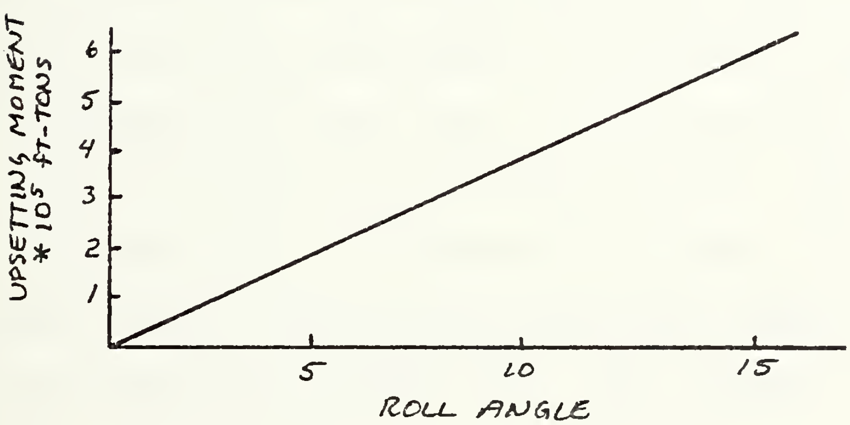


Figure 2.8 Upsetting Moment for Nearly Surfaced Barge

side barges raises GM by 1.45 ft but greatly decreases the righting capability of the side barges.

The system is unstable in pitch also, but the moment arms from the center of rotation to the barge end lift points are long enough that the additional required righting force is only 45% of its transverse value.

The worst case then becomes the load on one corner for a combined pitch and roll situation. For a combined 10° pitch and 15° roll the required restoring force on the extension at the corner is 1488 tons. Thus, a structural safety factor of 2:1 yields 3000 tons for the extension bracing.

A barge can normally absorb a load of 5% of its displacement without unduly affecting its stability. For the above case the load on the side barge is 3053 tons, requiring a barge displacement of 61,000 tons. This would mean a barge 475 ft x 250 ft x 36 ft ballasted to half draft. This will be a problem. Perhaps 3 sets of winches on the ends of four 600 ft barges, one per corner of the submerged barge, would provide better stability (Figure 2.9). This remains to be investigated.

Given the maximum load of 1500 tons it is now necessary to find a wire and machinery combination which is capable of making this lift. A steady rate of wire recovery

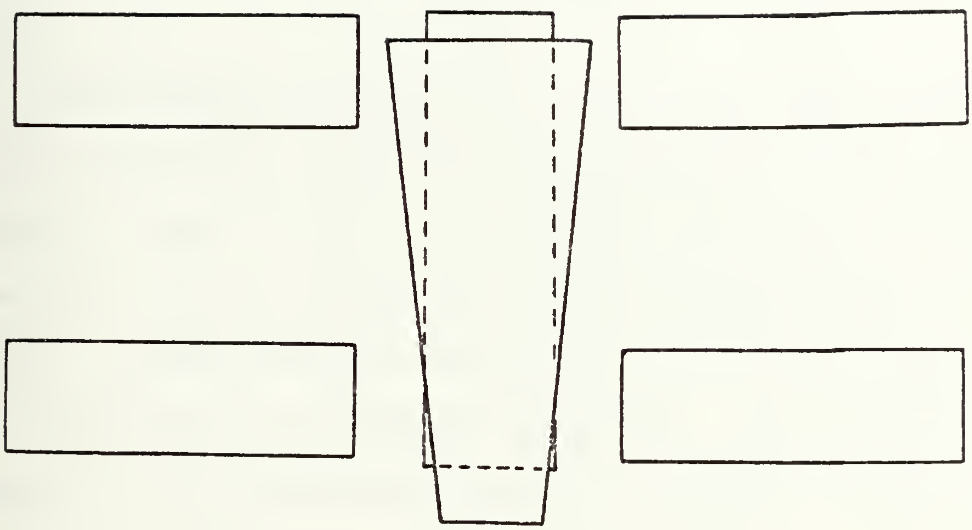


Figure 2.9 Alternative Side Barge Arrangement

is required on all 12 winches. Imposed upon that is the requirement to absorb a roll (or pitch), whether due to roll of the jacket or wave dynamics, and return the jacket to on upright position. It is recognized that the simple static model is only the roughest approximation of the actual stability situation and that work in this area is only just begun.

The breaking strength of 3 inch wire rope is 335 tons. Its working strength, one fifth of breaking strength, is therefore 67 tons. A lift of 1500 tons thus requires 23 parts of line and a 22 ton sheave block which becomes part of the load. A beam must be constructed to hold the upper block and the barge must be locally reinforced. To 60 to 200 ft submergence 4600 ft of cable will be required. The next step is to find a winch capable of handling 4600 ft of 3 inch wire with a 67 ton line pull on the outer winch drum wrap.

One of the largest capacity winches made is the SMATCO 100 Discovery Series,[15] which is capable of exerting a 63.4 ton line pull at 37 ft/min on the outer wrap of a drum designed for 5,000 ft of 3 inch wire. The 37 ft/min line speed means a hook speed of 1.61 ft/min. At that rate a 200 ft lift will require 5.4 hours, but that is only if the maximum righting moment is required. Otherwise, the lift will be much faster, i.e. a load of 24 tons allows a hook speed of 10 ft/min.

The winches at the stern of the lift barge require the lift capacity but not the drum capacity of the 100 . Discovery Series, but only the 100 and 84 Discovery Series can handle 3 inch wire. An 84 Discovery Series could be used at the lift barge stern. The characteristics of both winch series are given in Appendix B.

A case can be made for standardizing winches and thus easing coordination problems, but it must be kept in mind that the large 100 Series winch costs in the vicinity of $400,000 each, and for 12 winches, $3.6M is a very large investment. This is in addition to the required structural work on lift and side barges.

Traction winches were investigated and although there are over 600 winches for 2 3/4 - 3 1/2 inch wire in use, they are even more expensive than drum winches.[16]

Some thought was given to using motion compensators to ensure that no slack is allowed to develop in the lift system. These are expensive devices which can work well at low speed, but with a 15 sec wave period only 6 ft of relative motion (A 2.6° Roll) and one bite on the compensator, the compensator would be required to travel 18.4 ft/sec average speed for a 69 ft stroke in addition to keeping the cable taut in the lift blocks. A better solution to the relative motion problem would be to tune the side barge by ballasting to the natural frequency of the jacket/lift barge combination. This

would require continuous adjustment as the jacket is raised, however, and would still not solve the snap loading problem.

The final and possibly fatal problem with the side barge steadying system is the sudden loading of the lift wire due to wave action. The side barges can only be tuned for a specific, sinusoidal swell. Conceivably, unless the sea is dead calm, the lift barge could be dropping while the side barges are carried upward and the entire weight of barge and jacket be born by the lift wires . That is a dynamic problem beyond the scope of this thesis, but must be thoroughly investigated before use of this system is seriously considered.

2.7 Summary

Although the side barge steadying system appears to be workable, all areas require further investigation. In particular, the interaction of 3 roll and pitch coupled bodies in waves and the possible sizing of side barges to avoid over-straining the coupling wires should be determined.

There is an inherent conflict in using a side barge steadying system at sea. First, there is the requirement to keep slack out of the wires and a steady pull on the lift barge. Next, the lift barge must be capable of providing righting moment quickly and in the amount required. Finally, the side barges must be able to compensate for wave induced height

differences without applying an upsetting moment. These three requirements are separate but must be applied through the same set of wires.

A sophisticated sensing and control system is required, since line tension, side barge pitch and roll, and lift barge pitch, roll, depth, and ballast status must all be monitered, and line rate and lift barge ballast controlled. Even then this system may not work because of the rapid system response time required. Response time requirements should be the primary area for further study.

CHAPTER 3

CLAMP-ON PONTOON SYSTEM

3.1 Basic Concept

The major shortcoming of the side barge stability concept is its inability to take into account the relative motion of the side barges and the lift barge in roll. This problem is eliminated in the clamp-on pontoon system.

The submersible barge is retained, and the side barges as well, but the side barges are used only for positioning the lift barge and for pitch stability. Transverse stability is provided by pairs of vertical pontoons located on opposite outboard faces at one or more jacket levels (Figure 1.7). The pontoons are transported to the retraction site, flooded to neutral buoyancy, positioned, securely clamped in place, and pumped out completely or in stages, depending on the jacket's structural strength. The lift barge is then deballasted and the jacket transits the interface. The pontoons provide transverse stability until the barge deck pierces the air/sea interface.

With the stability source firmly fixed to the jacket/barge combination the attendant relative motion problems are minimized since now only pitch is controlled from a side or end barge. Further analysis may indicate that through proper

ballasting procedures, pitch support requirements can be minimized or eliminated completely.

Upon completion of the surfacing process the pontoons are removed by crane or they can be left in position if the jacket is to be transported directly to a new site and reinstalled.

This chapter reviews the system requirements and proposes a technique for sizing stability pontoons.

3.2 Assumptions

Several assumptions have been made and should be stated before the analysis of the clamp-on pontoon stability system continues. First, the submersible lift barge positioning and fendering system is the same as that of the barge described in Chapter 1, and the deballasting criteria are the same as well. In the stability analysis of the lift sequence the barge is assumed to rotate in pitch about the point of intersection of the extended upper and lower jacket faces as it surfaces. This is a mathematical convenience which does not necessarily reflect reality. Pitch stability was not considered as the stability analysis, it should be.

For conservative simplicity the jacket was assumed to have no waterplane area.

Pontoon weight was found using Jackson's criteria for submarine hulls of weight equals approximately one tenth displacement.[17]

Finally, this is a hydrostatic analysis which, although dynamics are not nearly so important as in the side barge system, is still a limitation. Almost arbitrarily the static stability criteria was taken to be a GM of greater than +1 foot. Any static stability criteria can be set and the methods in this chapter used to size the stabilizing pontoons.

3.3 Structure

New structural questions arise when the stability pontoons are secured to the submerged jacket. First, the pontoons must be secured to the jacket when the jacket is submerged. The launch pontoon of the North Sea Forties Field FA and FC jackets was joined at the lower end with a saddle and at the upper end with a hydraulic release. The same type of system could be used here, which would eliminate the requirement for at least four 190 foot dives. A candidate system is shown in Figure 3.1. The pontoon is positioned slightly below its final position, angled slightly outboard by lifting on the inboard side. It is then pushed against the jacket, raised to seat the jacket legs in the saddles, and pulled to the vertical. Hydraulic clamps then close hooks to complete the mating.

Next, the jacket must be able to withstand the upward force and transverse sagging moment imposed by the buoyant pontoons.

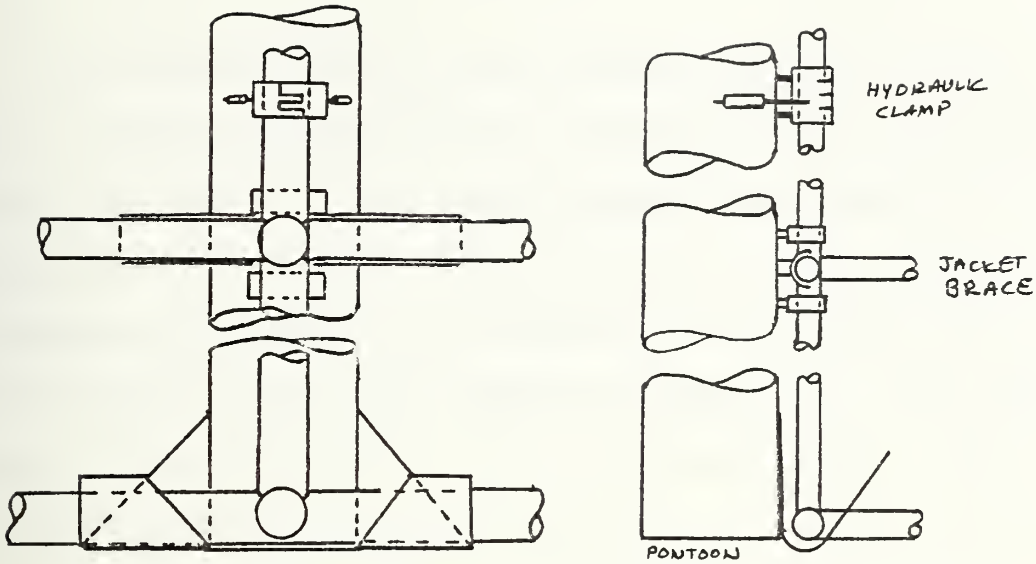


Figure 3.1 Clamp-On Pontoon Securing Mechanism

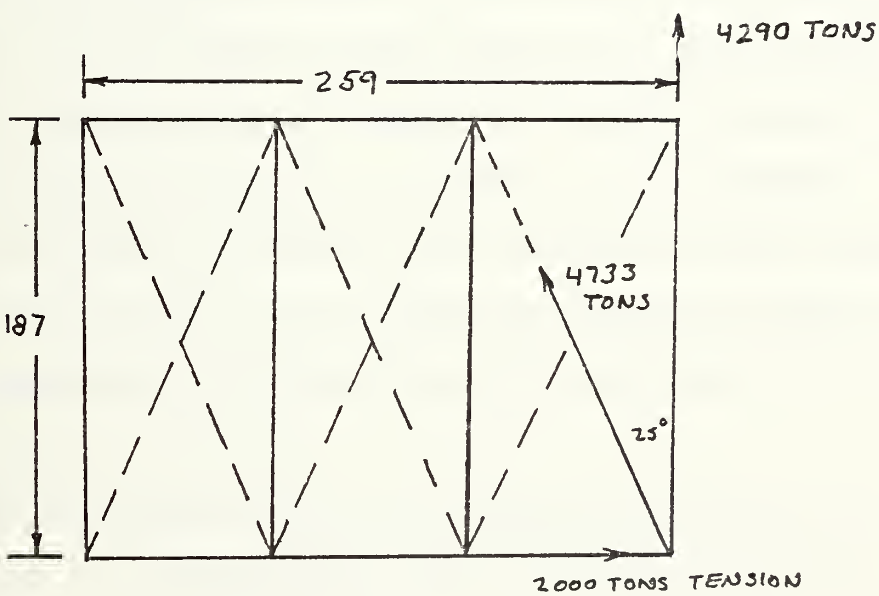


Figure 3.2 Buoyant Pontoon Force on Jacket

The buoyant force of the largest pontoon is 4,290 tons. A simple, two dimensional frame analysis is applied, assuming the jacket is neutrally buoyant and divided into 3 sections at the base with simple diagonal bracing (Figure 3.2). The compressive stress in the diagonal is 4733 tons and the tensile stress in the lower member is 2000 tons, requiring only 300 in^2 of mild steel for a 2:1 safety margin. This can be satisfied by a brace as small as 3 ft dia x 1 3/8 in thick.

In the corresponding surfaced condition the pontoon weight is 476 tons and from Figure 2.2 one third of the level one load is 1,606 tons. Even if the level one load is taken as acting at the extreme edge of the jacket the resulting total load of 2,082 tons is only 48% of the laod in the submerged condition, thus neither the weight load nor the buoyant load pose structural problems for the jacket.

Due to the 10° slope of the lower face the buoyant pontoon will also apply a longitudinal (jacket) moment on its securing mechanism. This must be accounted for in the clamp system design.

The pontoons will be preferentially located at levels 1 and 2 in that order, since level 1 provides the longest transverse righting arm of any point on the jacket and a given waterplane will be most beneficial when located at that point.

In the surfaced condition intact stability will be marginally less due to the addition of the pontoons. Without the pontoons the transverse GM 66.6 ft and with the pontoons this drops to 63 ft, only a 5% change. Therefore, while the weight addition should be taken into account, it is not considered significant.

3.4 Mathematical Model

The objective of using the math model is to determine the number, size and shape of the clamp-on pontoons. The basis of the transition calculations is the simple stability equation KB + BM - KG = GM. Equations were developed for each factor as a function of pontoon location and size, and jacket submergence at the longitudinal center of gravity of the jacket (X). The pontoons were considered to be hollow and weigh 10% of their displacement. The barge was assumed to be neutrally buoyant when floating at the interface.

Appendix C shows the detailed breakdown of the stability equation factors. More generally they are as follows:

$$KG = \frac{KG_{barge}\, W_{barge} + KG_{jacket}\, W_{jacket} + \Sigma\, KG_{pontoon}\, W_{pontoon}}{W_{barge} + W_{jacket} + \Sigma\, W_{pontoon}} \tag{3.1}$$

Variations that must be accounted for in barge weight include the decrease in ballast due to the loss of buoyancy as the

jacket emerges and the increase in ballast required due to pontoon submergence.

Buoyancy is much simpler because it is calculated strictly on the basis of volume.

$$KB = \frac{KB_{barge}\ B_{barge} + KB_{jacket}\ B_{jacket} + \Sigma\ KB_{pontoon}\ B_{pontoon}}{B_{barge} + B_{jacket} + \Sigma\ B_{pontoon}} \tag{3.2}$$

In calculating KB care must be taken to ensure that only the submerged portion of the pontoon is used and that $KB_{pontoon}$ extends only to the center of buoyancy of the pontoon.

The final factor used to calculate GM is BM.

$$BM = \frac{I}{\nabla} = \frac{\Sigma\ \pi R^2\ (r + R)^2}{\nabla_{barge} + \nabla_{jacket} + \Sigma\ \nabla_{pontoon}}$$

For stability purposes the jacket was not assumed to have waterplane. R is the pontoon radius and r is the offset. It should be noted that this form of the BM calculation will result in an asymmetric pontoon having a vertical face adjacent to the jacket. An alternate form is a constant-offset symmetric pontoon, which has a more complex clamping system due to the pontoon's taper (Figure 3.3).

GM could be calculated for any submergence and unless other provisions were made the model assumed a constant radius for the entire pontoon. In later stages of analysis different

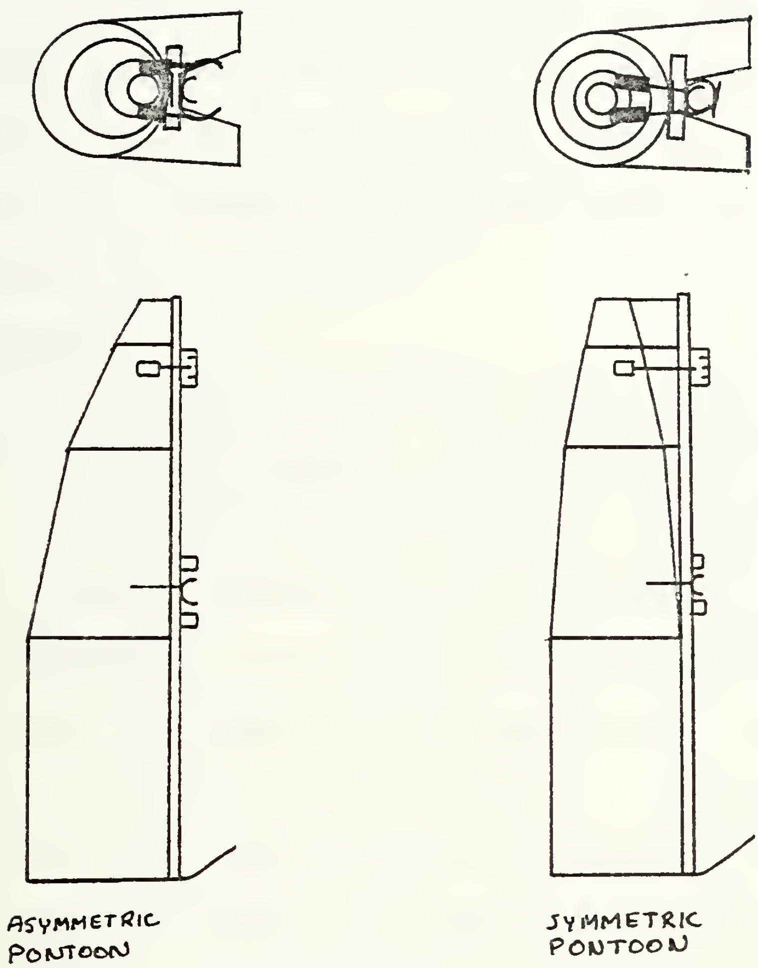


Figure 3.3 Pontoon Bracing

pontoon sizes were used for different levels, and tapered sections below the waterline at each level could be resolved into a cylindrical "equivalent pontoon" having the same buoyancy weight and centers of buoyancy and gravity as the tapered pontoon. This minimized the volume error resulting from use of a cylinder vice a conical section below the waterline.

The HP-41C program used for these calculations is given in AppendiX D.

3.5 Procedure

An initial set of calculations was used to roughly determine pontoon requirements. A calculating run consisted of finding the BM as a function of jacket submergence at the longitudinal center of gravity at 20 ft submergence increments from 0.0 ft (surfaced) to 146.6 ft (fully submerged). Pontoons were always added in pairs. A plot was made for sets of 2, 4, 6, and 8 pontoons (Figures 3.4-3.7). Two pontoons were located at each jacket elevation beginning at level 1. For example the six pontoon plot uses two pontoons each at levels 1, 2, and 3. On each plot runs were made for either five or six different radii, each line on the graph representing run with all pontoons having the same radius and extending from the lower face to the upper face of the jacket.

Keeping in mind the GM > 1ft requirement and the advantages of minimizing the number as well as the size of

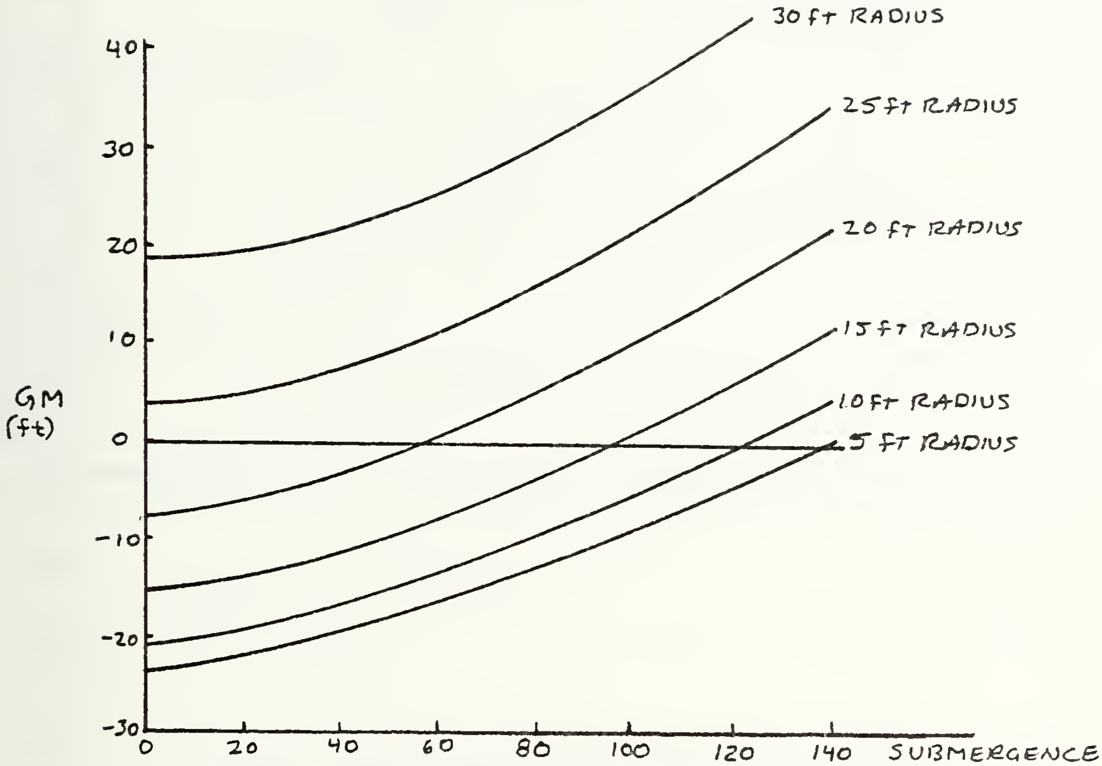


Figure 3.4 GM vs. Submergence, 2 Pontoons

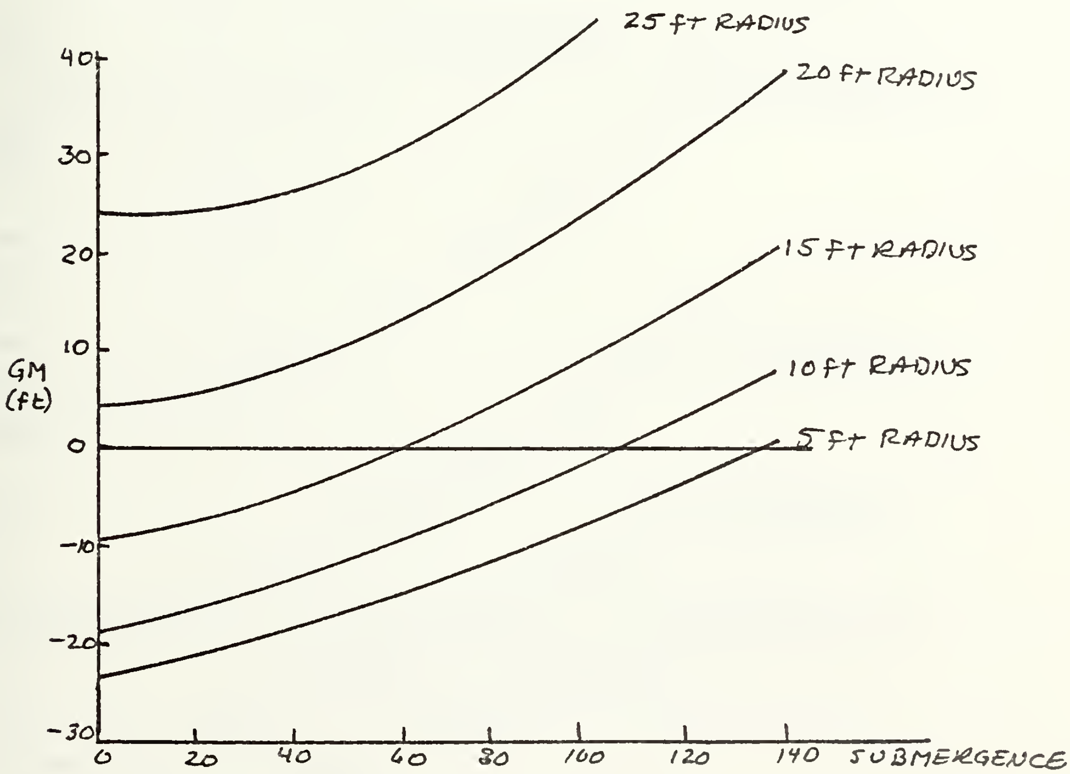


Figure 3.5 GM vs. Submergence, 4 Pontoons

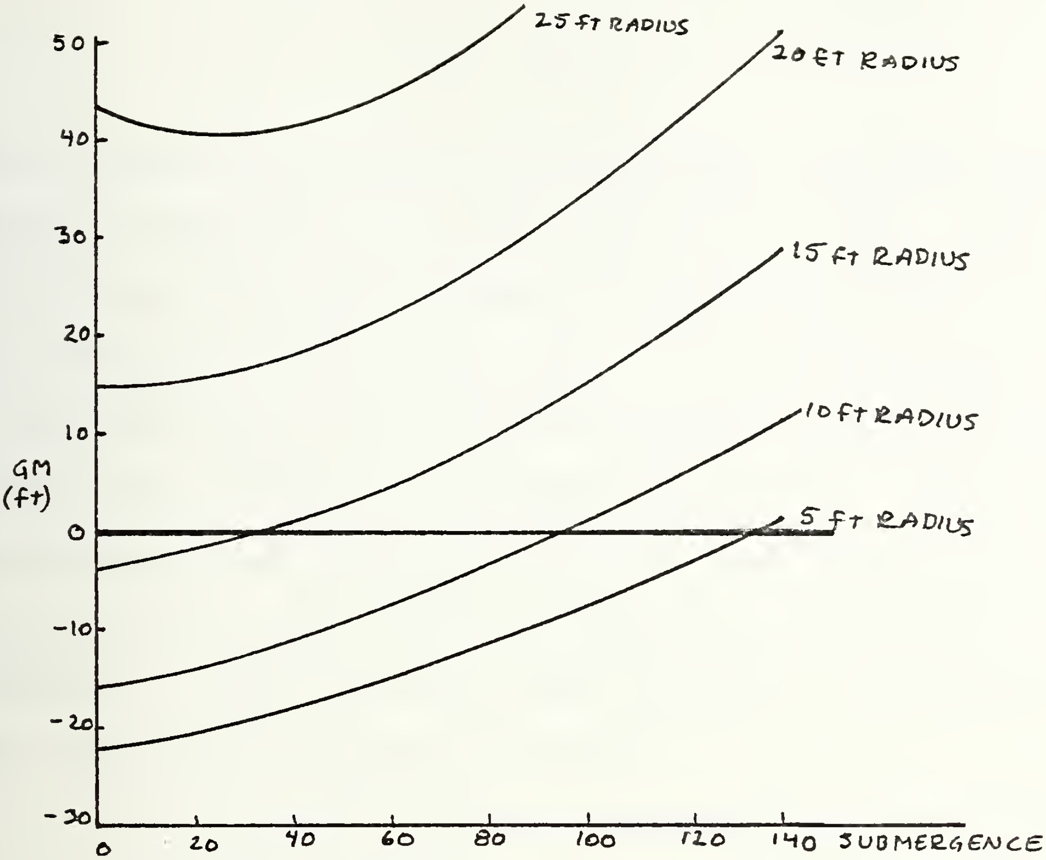


Figure 3.6 GM vs. Submergence, 6 Pontoons

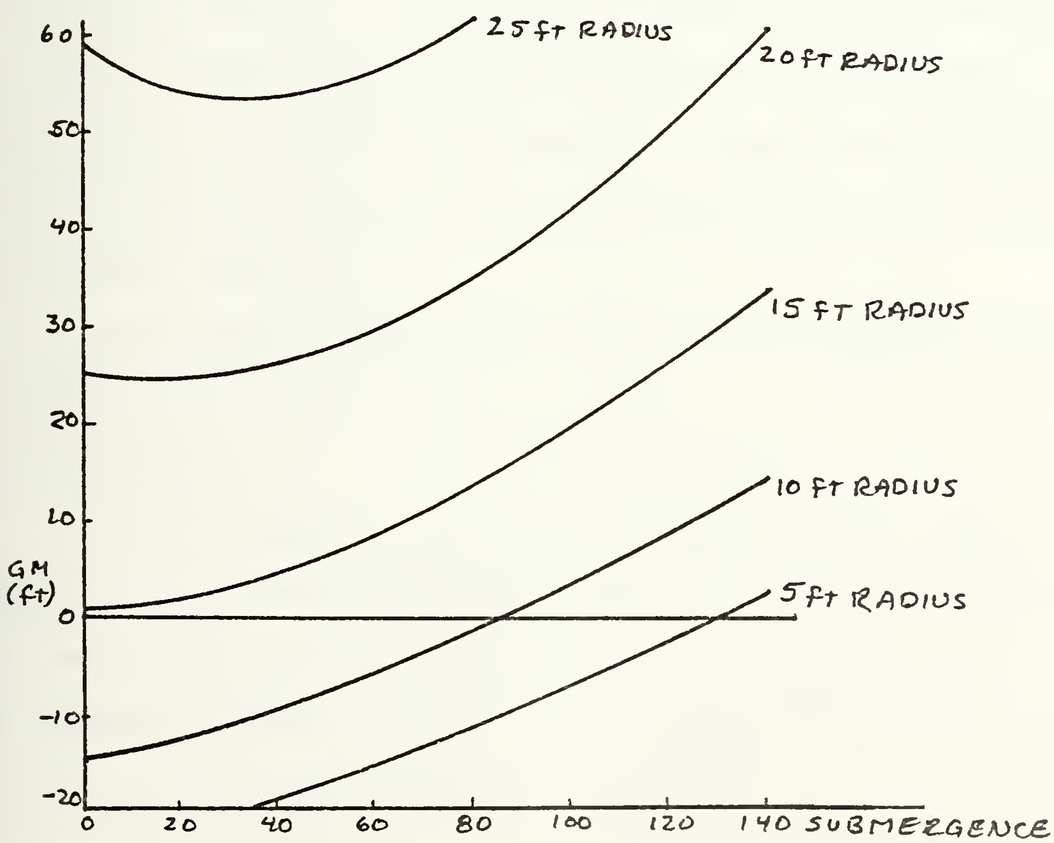


Figure 3.7 GM vs. Submergence, 8 Pontoons

the pontoons required at zero submergence, combinations of pontoon numbers and sizes were run at that point. When a satisfactory solution was determined, the jacket was submerged two feet and GM again calculated. If GM became greater than 2 feet the radius of the pair of pontoons farthest from the jacket base (highest level number and smallest offset) was reduced and GM recalculated. In this fashion the pontoons were tapered at the air-sea interface as the entire system submerged. When a pontoon radius reached 0, tapering of the next set of pontoons was begun.

As the tapered section submerged, a low buoyancy error developed since the pontoon was modeled as a cylinder with a radius equal to the pontoon radius at the interface. This was periodically corrected as the barge submerged by calculating an "equivalent pontoon" for the pontoon volume extending from the bottom face of the jacket to just below the air/sea interface.

Calculations were made for both the symmetric and non-symmetric pontoon cases.

3.6 Results

From looking at the four constant radius graphs several things are immediately apparent. First, as anticipated, the least stable position is at zero submergence in all cases. The jacket is almost clear of the water and the center of buoyancy is at the midpoint of the barge.

Second, as could also be anticipated, increasing the number of pontoons spreads the radius lines, particularly at larger radii. More pontoons provide more stability. However, adding pontoons has proportionally less and less effect because the offset, which is a squared factor in BM, is diminished for each additional pair of pontoons.

Next, as the barge submerges the center of buoyancy rises and the center of gravity drops due to increased ballast in the barge. Thus, less waterplane and smaller radius pontoons are required to maintain a positive GM.

An interesting phenomenon is that, particularly for large numbers of large radius pontoons, GM actually begins to increase as submergence decreases. This was found to be due to the rapid decrease in submerged volume in the denominator of the BM factor as the jacket surfaced.

The next step was to select the number of pontoons. Much of this decision process was subjective, and for a real case a decision strategy should be implemented which takes into account design, material, and fabrication costs, structural considerations, and at-sea handling capabilities.

If only two pontoons are used on level 1 a minimum radius of 25 ft is required. The problems associated with fabrication and handling two 50 ft diameter pontoons over

120 ft long are enormous. Therefore, a minimum of four 19 foot radius pontoons are required. On the high end, to manufacture six pontoons vice four requires 50% more effort to reduce the average radius by only about four feet. This was not considered to be cost effective. Thus, four became the optimum number of pontoons.

Taking advantage of the opportunity to vary the radii between platform levels, different combinations were tried before settling on a level 1 radius of 21 ft for what were obviously going to be tall pontoons and 16 ft for the shorter level 2 pontoons. GM for this combination was + 1.3. The resultant pontoons are shown in Figure 3.8.

While submergence is measured at the center of gravity of the jacket the pontoon heights are taken at their local positions. Full submergence depths are therefore 187 ft at level 1, 161.95 ft at level 2 and 146.6 ft at the jacket center of gravity.

Submergence was increased and runs were made at short intervals. At 13.6 ft submergence, 15 ft at the level 2 pontoons, a GM of + 2 had been reached and tapering of the level 2 pontoons could begin. The radius of the level 1 pontoon was maintained at 21 ft.

As the jacket submerged the favorable shift of the centers of buoyancy and gravity allowed an increased rate of

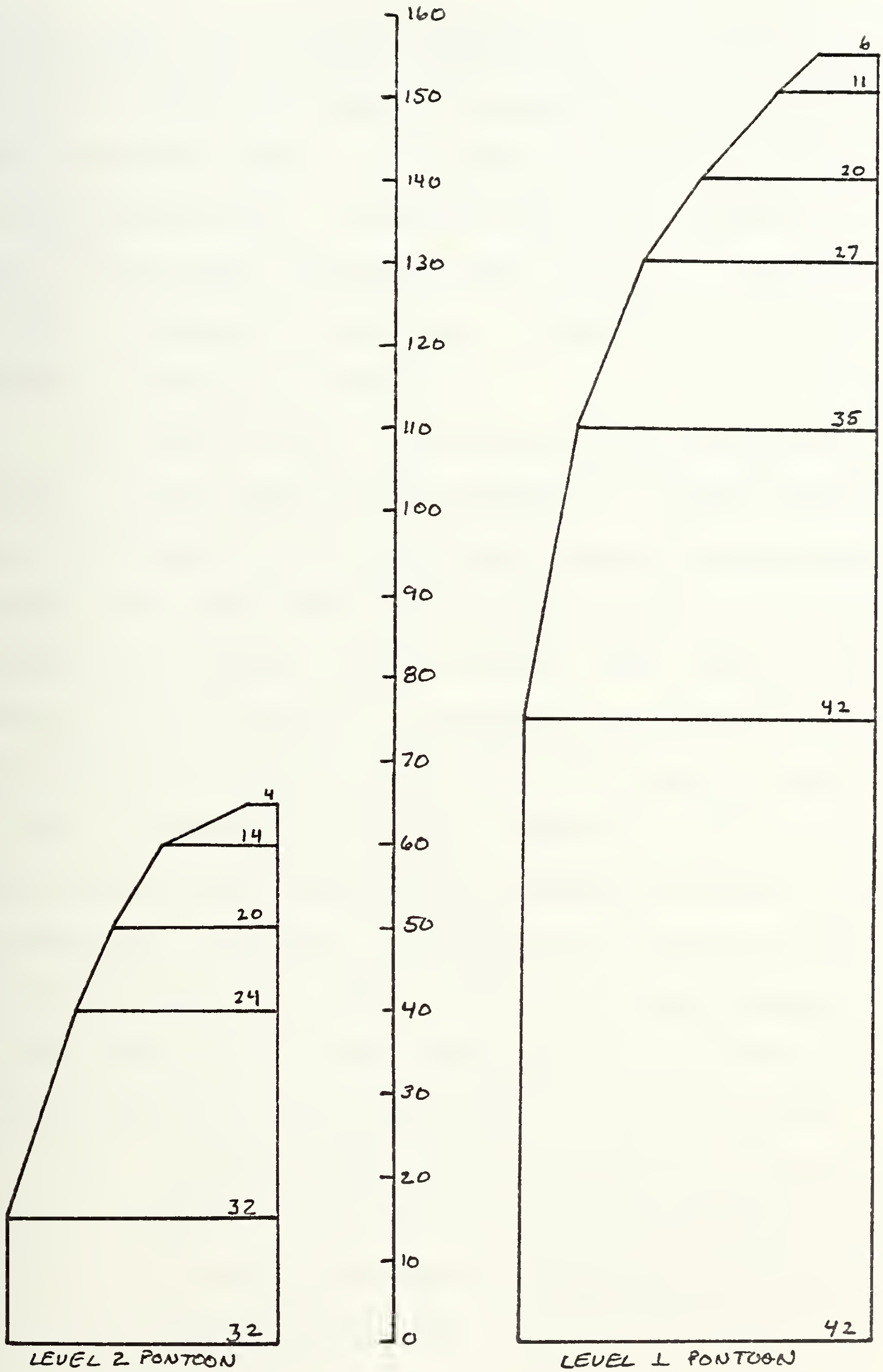


Figure 3.8 Asymmetric Clamp-On Pontoon

pontoon taper. At a jacket submergence of 58.9 ft the 64 ft high level 2 pontoons could be terminated and tapering of the level 1 pontoons began. At a jacket submergence 120.7 ft the 154 ft high level 1 pontoons could be terminated, 23 feet short of the fully submerged level 1 depth. GM increased as jacket submergence continued. A plot of GM vs. submergence is shown in Figure 3.9.

The rate of taper, particularly of the level 1 pontoons, is the result of a trade-off. A rapid initial taper is effective in lowering BM to keep GM from getting to high. The taper stays relatively constant and results in a longer more slender type one pontoon (see Figure 3.10). However, for the pontoon to terminate the center of buoyancy of the system must have risen above the center of gravity, KB > KG, so that BM is no longer required. This calls for a lower initial taper and rapidly increasing buoyancy and KB as submergence increases. This type two pontoon tapers rapidly near the top. While a longer, slender cylinder may have higher fabrication costs and be more difficult to handle, short stubby cylinders have two disadvantages:

1. A large upper surface or a very high rate of taper near the top will produce high transient forces as the pontoon dynamically crosses the air/sea interface.

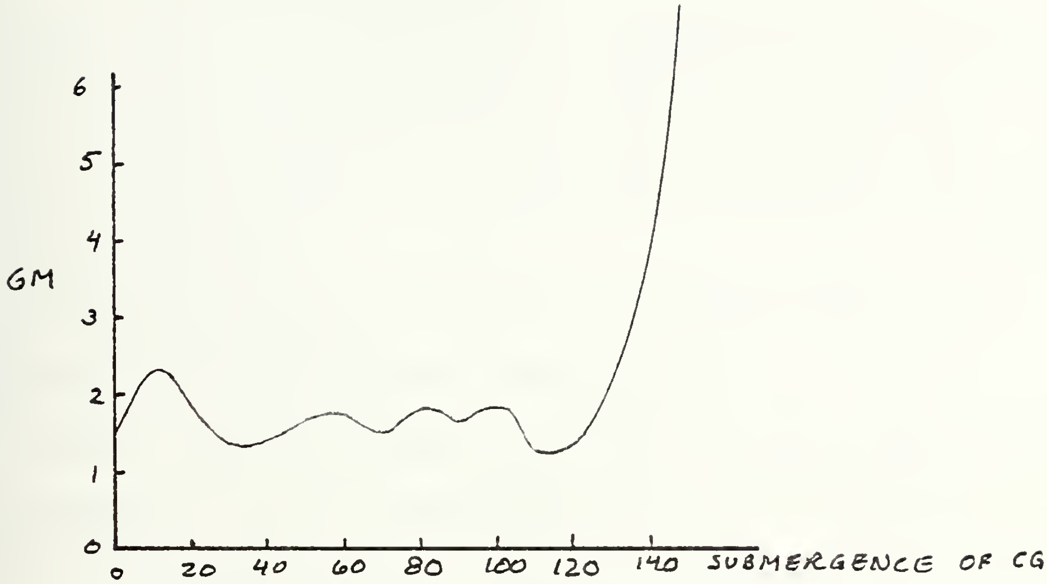


Figure 3.9 GM vs. Center of Gravity Submergence for Asymmetric Pontoons

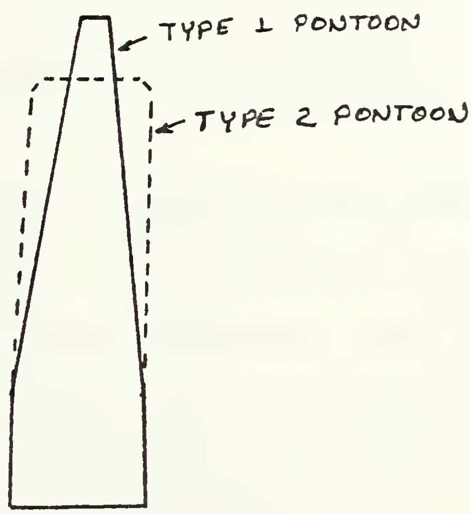


Figure 3.10 Type 1 and Type 2 Pontoons

2. The shorter pontoon can distribute its buoyant forces over a much smaller area of jacket bracing and increased point loadings will result.

A compromise must be envolved, perhaps maintaining a range of positive GM as was done here.

As was stated earlier, one option in the clamp-on pontoon concept is to use symmetric pontoons. The only advantage to doing so is that a constant offset is maintained, thus, affording increased BM as the pontoon is tapered. The disadvantage is that the clamping braces must be extended out from the tapering pontoon to a vertical line parallel with the outboard jacket face. For these calculations the level 2 pontoons were taken to be the same as in the symmetric case.

The resulting level 1 pontoons were essentially the same as the asymmetric case. The two differences were that at the point of maximum radius difference the symmetric pontoon was 1 foot more slender than the asymmetric pontoon and the asymmetric pontoon was taller by 1 foot. These differences are within the variations permitted by a 1 foot wide GM criterion.

3.7 Summary

The clamp-on pontoon is a viable concept and a major improvement over the side barge stability idea. It has greatly reduced side barge requirements but the question of pitch stability still remains. One possible solution is to provide a pair of clamp-on pontoons for pitch stability at the level seven end of the jacket. This would also provide stability in a combined pitch and roll situation. Further investigation is required.

The clamp-on pontoon concept has also permitted the maintenance of a known GM at every submergence. The waterplane associated with the BM factor is rigidly attached to the barge and responds immediately and provides sufficient righting moment as the jacket/barge combination rolls. A righting arm curve still needs to be drawn, and it will change for each submergence as the shape and volume of the underwater portion of the system changes.

Another unresolved problem is the initial positioning of the barge over the jacket. There is still no direct guiding linkage between the jacket and the barge until the guide/fendering system comes into play.

A final shortcoming of the clamp-on pontoon concept is that as closely as these pontoons were sized they are virtually jacket-specific. Perhaps GM could be allowed to

rise and the pontoons made oversize. Then only the clamping system would possibly require alteration. The alternative is to use a classing philosophy such as is used for ships. Jackets with similar environmental requirements and mission demands could come from one design and be built alike. Millions of dollars would be saved on design and testing alone. There would also be substantial savings through reuse of the same pontoons to recover a number of similar jackets.

CHAPTER 4

STABLE BARGE

4.1 Basic Concept

As discussed in the introduction the basic concept of the stable barge system is that two tower-like superstructures located on the aft portion of a wide submersible barge provide transverse stability as the barge and jacket are raised through the air/sea interface. When compared to the clamp-on pontoon concept this system provides a further simplification of at-sea handling since the source of transverse stability is part of the barge itself rather than something to be mated to it on site.

The superstructures contribute to stability by providing both buoyancy and waterplane area. They can almost be thought of as drydock wing walls. The barge has been widened to 200 ft and the length retained at 580 ft. Because the transverse lever arm was less than either the level 1 or level 2 clamp-on pontoons a superstructure overhang to port and starboard was required. If the barge is lengthened as well as widened submerged volume will increase, lowering KB, KG will decrease and BM may increase. This requires further investigation.

The superstructures are watertight, but because they are at the high end of the submerged barge they do not have to

submerge as far as the bow and therefore structural requirements will not be as great.

The barge is submerged as before. However, as will be shown later, the superstructures are not completely submerged and a work area approximately 20 ft x 20 ft is retained on the top of each superstructure even with the barge in position to receive the jacket.

Winches can be located on these work area and the fixed barge points can be of tremendous help in accurately positioning the jacket over the barge.

Pitch steadying barges are still required at the bow of the submerged barge during the mating process but may possibly be eliminated after the lift begins. The fendering system is the same as in the side barge and clamp-on pontoon systems. Although more accurate initial positioning is possible with the stable barge, a fine positioning and landing system is still required.

Once the jacket and barge are mated the barge is again deballasted for transition.

4.2 Assumptions

The assumptions required for the stable barge system are the same as those made for the clamp-on pontoons.

If the barge bow is deballasted initially, an up pitching moment will be applied to the barge. This will in

turn cause the reserve buoyancy of the barge superstructures to diminish. The result will be a stable pitch situation. As the barge is evenly deballasted more reserve buoyancy becomes available aft and more pitch stabilizing moment can be applied by deballasting forward. This combination of even deballasting and pitch-up ballasting shown can be continued until the barge surfaces.

For purposes of the mathematical analysis used to develop these superstructure shapes pitch is again assumed to be about a point on the surface of the water where the extended lines of the upper and lower jacket faces intersect.

Pitch was not considered in sizing the superstructures. The next step in modelling sophistication should take pitch into account.

Superstructure weight was still taken as 10% of volume even though the structure is not cylindrical and cannot take advantage of a cylinder's structural strength in compression.

4.3 Structure and Environmental Loading

The ABS offshore barge rules indicate that as the barge width is increased from 160 ft to 200 ft for a constant length of 580 ft a corresponding 25% increase in section modulus will be required.[18] This can be accomplished by increasing either the longitudinal scantlings or the depth. If the length is also increased a further increase in section modulus is necessary.

The increased 200 ft beam also provides a substantial increase in intact stability over the narrower lift barge, but this is offset somewhat by the barge superstructure weight. The surfaced GM is 157 ft and the radius of gyration is 80 ft, which gives a roll period of about 7 seconds. This is a very stiff system. Trim ballast provides a draft of 15.5 ft.

Further dynamic investigation is required to determine if the short natural period will put too much stress on the jacket restraints. The barge could be ballasted to reduce GM and lengthen the roll period, but increased submergence would come into conflict with the Code of Federal Regulations freeboard requirements which specify 92.6 in. freeboard for a 580 ft tank barge.[19] When the barge is deepened to generate sufficient freeboard the section modulus will have increased which in turn allows the barge to be lengthened.

Using the ABS mobile offshore drilling unit equations for wind loading:[20]

$$\text{Force} = \frac{.00338}{2240} (V_k)^2 \; C_h \; C_s \; A$$

The superstructure derived later in this chapter has height and shape coefficients of 1.0 and an area of 10438 ft^2. For a 100 KT design wind this yields a wind force of 158 tons with a centroid height of 43 ft. A moment of 6773 ft tons is

provided at the waterline. The jacket shielded by the superstructure has a shape coefficient of .6, therefore, the net force increase is 60 tons. The force on the barge and jacket alone is 986 tons, thus there has been a 6% increase in force and a 2820 ft ton (5%) increase in rolling moment at the waterline. Neither of these is considered significant.

In a very simplistic way wave loading was taken to be a 50 year North Atlantic wave of 100 ft positioned statically against the outboard side of the superstructure. The shear and bending moments at the deck level were then calculated to give an order of magnitude approximation of the structural requirements. It is realized that this model will underestimate the impact forces, especially since the barge is so stiff, and will overestimate the wave height at the side.

For a superstructure length of 158 ft the moment per longitudinal foot is 2428 ft tons. At this narrowest point, the forward end, the superstructure is 20 ft wide (Figure 4.1).

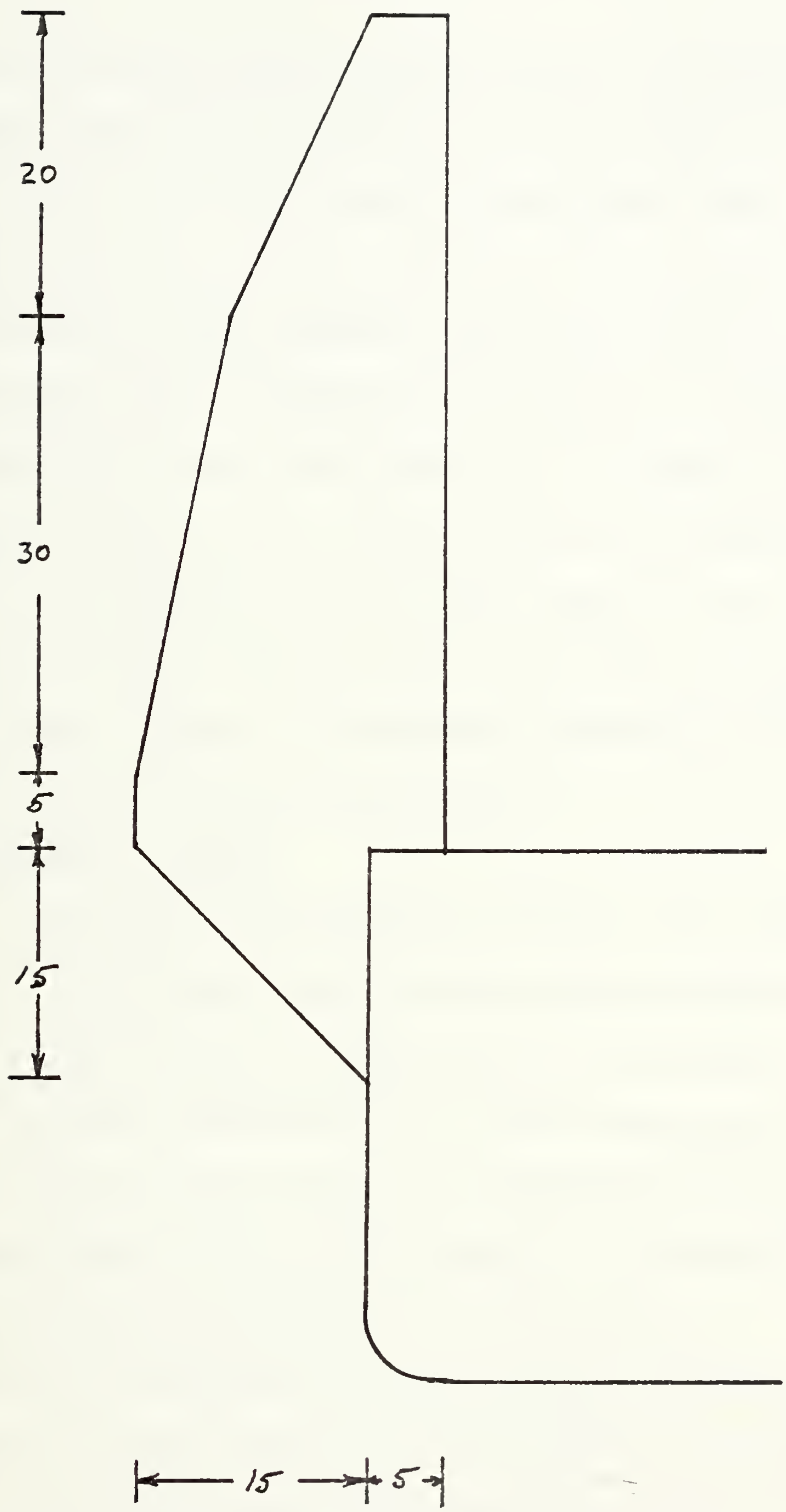


Figure 4.1 Forward End of Starboard Superstructure (Facing Aft)

If the forward superstructure face is pivoted in a vertical plane about its inboard corner the tensile force on the outboard plate is 22663 pounds/linear inch. The inward pressure due to the static head of 79.5 ft is 35 psi. For a 2 ft longitudinal frame spacing the shear force at the base is 420 lb/linear inch. Simple vector addition yields a total stress of 22670 lb/linear inch upward at 1° inboard from the vertical. For a plate only one inch thick the tensile force is 22670 psi, or 76% of yeild for mild steel. For a dynamic loading factor of 1.2, one inch plate will not provide sufficient safety margin. It must be reemphasized that this is only the roughest of approximations.

4.4 Mathematical Model

The except for configuration changes, the mathematical model used for the stable barge calculations is the same as the one used for the clamp-on pontoons and discussed in Chapter 2. Although submergence is still measured to the lower face of the jacket at the center of gravity the buoyant superstructures begin at the barge deck, 3 ft below the jacket and this was accounted for in the model.

There is a weakness in this modeling technique which is not a factor in the clamp-on pontoon model. For the purpose of determining local submergence the pontoon can be taken as a point location. The wide barge superstructure,

however, extends over 150 ft longitudinally and keeping in mind the modelling of pitch rotation, the local submergence over the length of the superstructure changes by 30.7 ft at maximum submergence.

The submergence difference has been taken into account in a realistic but conservative manner. As less waterplane area is required for deeper submergence the superstructure is first tapered inward all along its length to eliminate the overhang. As submergence increases, superstructure length is reduced, moving from forward to aft. This step not only is most effective for stability purposes, but minimizes discrepancies due to superstructure length as submergence increases.

Superstructure submergence has been represented by submergence at a point 34 ft forward of the transom which has a maximum submergence of 88 ft. Because the waterplane cuts the superstructure at an angle, the waterplane is overestimated and the buoyancy is underestimated for center of gravity submergence of less than 118 ft (71 ft local). At submergence deeper than 118 ft both buoyancy and waterplane are underestimated and hence conservative since there is no longer waterplane forward of the 34 ft calculation point.

At center of gravity submergences of less than 72 ft (43 ft local) waterplane error is minimized since the line

joining the center of pitch rotation with the forward limit of superstructure waterplane passes through 43 ft submergence at the calculation point and again the submerged volume is overestimated.

The next programming refinement should take this into account by using a more realistically determined calculation point which will result in compensating errors. It would be even more desirable to use a program which calculated pitch stability as well as roll stability.

4.5 Procedure

The goal, as in Chapter 3, is to minimize the cost and fabrication requirements by minimizing the size of the barge superstructures required to maintain a static stability of GM > 1.0. Size should also be minimized to reduce wave and wind loading.

There is a temptation to locate the interior superstructure walls as close as possible to the jacket. However, except for rubbing strips these walls are unprotected and a relative roll during the positioning and mating process can put enormous point loads on the jacket and the superstructure (Figure 4.2). A 5° relative roll criteria was established and the inner superstructure walls located to permit a 5° relative roll between the jacket and barge when the jacket is in position longitudinally.

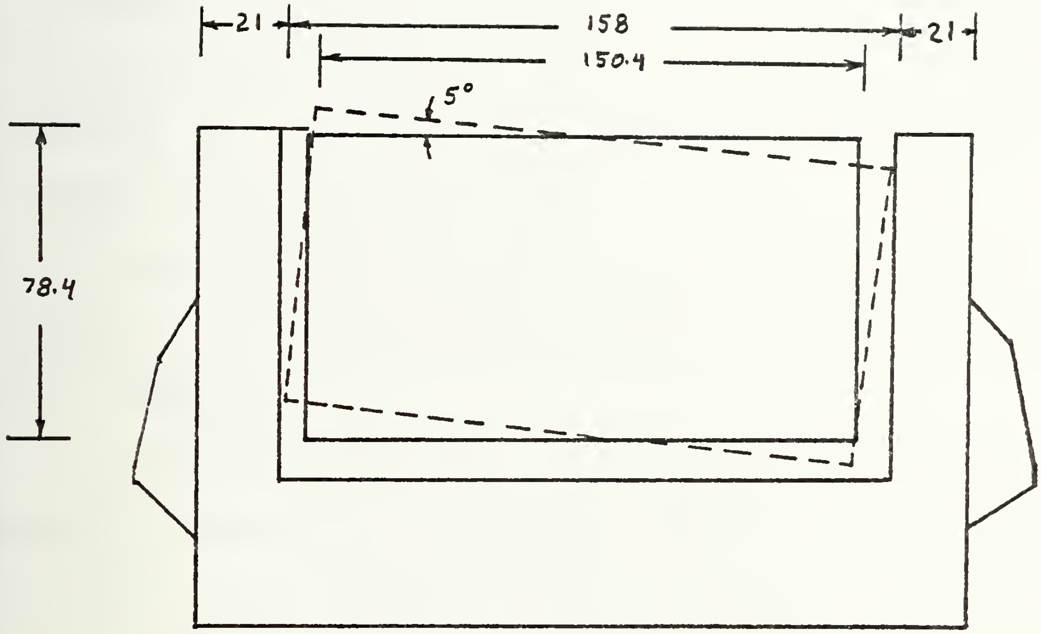


Figure 4.2 5° Relative Roll Criterion at Transom

As before, the initial calculations were made at zero submergence. Required waterplane area, shape, and offset were then determined. In this case an overhang was required to generate the required stability and as the barge submerged the overhang was reduced to zero. Then the structure was reduced by shifting the forward edge of the waterplane aft as the barge continued to submerge.

An "equivalent superstructure" concept was again employed to minimize volume error due to changing waterplane.

4.6 Results

The basic superstructure shape was a trapazoid 158 ft long, 21 ft wide at the stern and 5 ft wide at the forward end (Figure 4.3). These dimensions were set by barge and jacket dimensions and relative roll criteria.

From the initial zero submergence calculations it was obvious that, given the area available on the port and starboard quarters of the barge, there was not enough waterplane to generate a large enough BM for GM to be greater than +1. Also, the effect of submerging the very large barge was to reduce BM. It thus became necessary to provide a superstructure overhang to port and starboard running the length of the superstructure and wide enough to create the required waterplane. A 15 ft overhang on each side was required. To avoid stress concentrations, protect against wave impact,

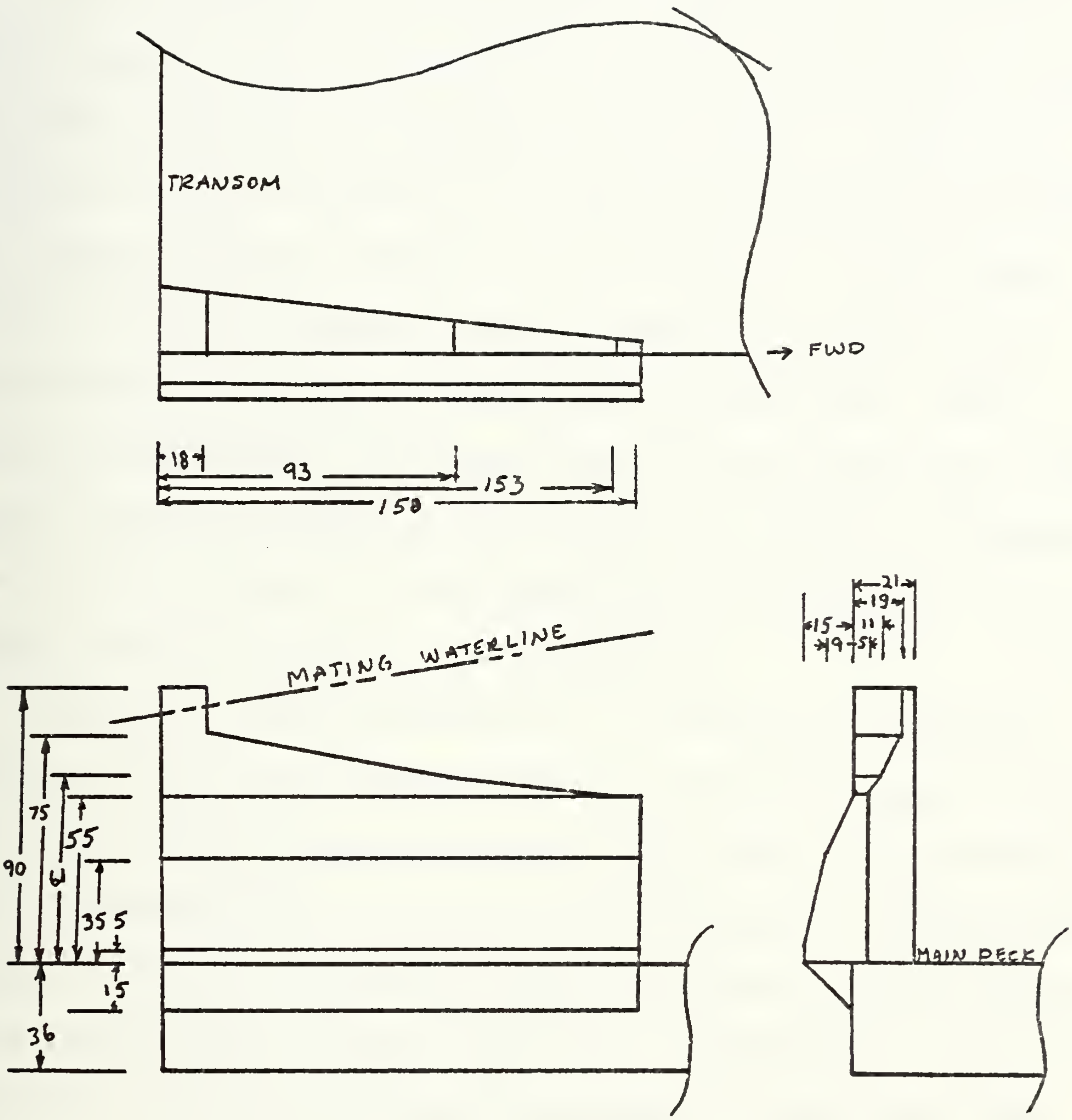


Figure 4.3 Starboard Stable Barge Superstructure

and help build buoyancy at 45° sponson was installed under the overhang.

As in Chapter 3 the barge was submerged and calculation runs were made at short intervals. Initial reductions in water-plant area were made by reducing the overhangs. Next, the waterplane at the forward end of the superstructure was reduced since, being narrower than the superstructure aft and hence providing little waterplane, large reductions in structure could be made with a small increase in submergence. Also, keeping superstructure aft means that the required local superstructure height to reach a given center of gravity submergence is less than it would be with superstructure forward. This provides another saving in superstructure.

Since the superstructure is a substantially smaller percentage of the lift barge volume in the stable barge system than in the clamp-on pontoon system (5.9% vice 8.0%) buoyancy of the superstructures is not as large a factor in maintaining stability. It was increasing pontoon buoyancy in the clamp-on pontoon system which allowed the level 1 pontoons to terminate 30 ft below the fully submerged waterline. That is not the case in the stable barge system, in which the superstructure can end only 8 ft below the fully submerged waterline at the calculation point. Since the calculation point is 16 ft forward of the forward end of the superstructure waterplane

at full submergence, the actual forward superstructure depth is 85 ft and the aft submergence is only 81 ft. This is illustrated more clearly in Figure 4.3.

Because the superstructure terminated so close to the surface it was decided to continue the superstructure through the surface with a minimum 5 ft freeboard. The resulting work platform does not submerge at any time. It is a splendid location for positioning winches and the first exact barge/ jacket position reference of the systems thus far discussed. The jacket can now be located exactly over its landing point using references and winch points which are all on the surface and can be put in precise relative positions. This is a tremendous advantage at sea. Platforms also provide access for deballast air.

A curve of GM vs. submergence was again constructed (Figure 4.4). Again, GM was always greater than + 1.0. The rise in GM as maximum submergence is approached is due to the extension of the superstructure through the air/sea interface.

The superstructure extension through the interface also improves pitch stability by providing reserve buoyancy on one end of the pitch righting arm. A minimum pitch righting force of about 103 tons is available on a 280 ft arm in the fully submerged condition. Unfortunately, it is only on the stern, but it means that less precise pitch moment control is necessary at the bow.

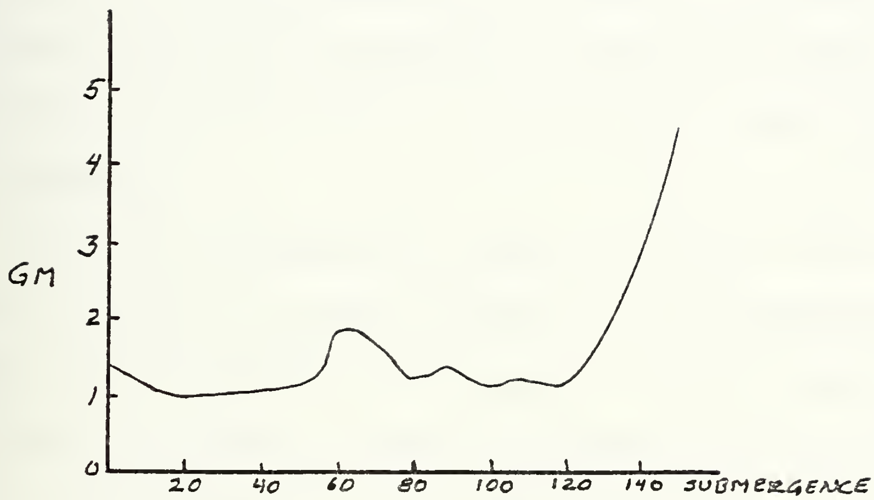


Figure 4.4 GM vs. Submergence for Stable Barge

Longitudinal GM in the fully submerged condition is 9.7 ft. However, that is deceptive since trimming 5 ft by the stern, i.e. 0.49° will put the work platforms awash. If the barge is rotated upward as assumed in the math model longitudinal GM quickly becomes very large and the barge can be deballasted forward to provide pitch stability.

4.7 Summary

Given the assumptions made earlier the stable barge stability system is a viable concept. It is recognized that the barge length and hull depth are no longer proportional to the beam. However, a length increase will help pitch stability even though it will mean less taper of the superstructure as the barge submerges because of the decreased influence of superstructure volume on KB.

The stable barge is jacket specific in the fendering and landing system and in the superstructure shape, which can be oversized to accommodate a number of different jackets.

There is some technical risk in both the structure and seakeeping of a 200 ft wide barge. Transverse shear and bending moment calculations will be required as well as extensive dynamic analysis. Further analysis of the superstructures is also required.

The stable barge will be expensive, but if a generally applicable barge design can create and a jacket classing philosophy followed then overall costs, including reinstallation vice new construction, can be reduced.

CHAPTER 5

PONTOON BARGE

5.1 Basic Concept

The baseline of the pontoon barge retrieval system is the North Forties FA and FC pontoon barge installation system discussed by Blight.[5] This is the first concept investigated thus far in which a total system approach was taken by the designers of the baseline system.

The jacket was constructed on a barge-like series of interconnected pontoons in a drydock. Two large spheres were attached to the upper legs to "catch" the jacket as it pitches up during the installation process, in the same fashion as the large upper leg sections in Figure 1.4 stabilize a self-floating tower.

In transit the pontoon barge provides buoyancy, intact and damage stability, and all the other ship-like functions of a barge.

At the installation site the sequence flooding steps described in Chapter 1 takes place. The pontoon sections under the base of the jacket are flooded first. The aft end of the barge sinks and at a critical pitch of about 13° the water plane suddenly drops as the tower becomes unstable in pitch, pitching up rapidly until caught and stabilized by

the 51 ft diameter spheres mounted on the upper legs. Selective flooding is continued through steps similar to those in Figure 1.4 until the tower has landed.

During the installation process the pontoon barge remains securely attached to the tower. After the tower is on the bottom the pontoon is ballasted to neutral buoyancy and upon release of hydraulic attaching mechanisms at the top of the barge, it is lowered out of a saddle near the base and removed to the surface using umbilical-supplied compressed air. The spheres are removed in a similar manner.

This system was originally intended for North Sea use where structural considerations dictate weight to buoyancy ratios of greater than one, and some sort of auxiliary flotation is required. The decision to use a pontoon barge instead of 2 enlarged jacket flotation legs was made on the basis of wave-induced shear loads and upsetting moments due to drag of the large legs near the sea surface.

The concept of system design emerges here for the first time. Two pontoon barges were constructed and each barge launched two jackets. It is common to re-use standard launch barges and a purpose-built launch barge is a rarity. But here the two jackets for each pontoon were nearly identical. This permits a much tighter barge design, with smaller margins and more efficient use of materials.

For retraction the reverse of the above process is carried out. Using this system for retraction presents some difficulties. First, the jacket is grouted to piles driven into the bottom. The piles can be severed below the mudline, however the reworking of the grout-filled pile guides is a major effort. A pile system such as that discussed in Section 6.3 would eliminate the grouting problem.

Next, as with the buoyant tower discussed in the next chapter, the system is unstable in pitch during the first rotation until caught by the steadying spheres, and it remains unstable in roll until flooding has increased the weight sufficiently for transverse GM to become positive again.

Finally, mating of large objects at sea is frequently a difficult and dangerous job. Mating the two 51 ft diameter spheres with the jacket at a depth of over 260 ft will be particularly tough.

Other than elevated attachment and support stress there is nothing inherently wrong with pitch instability so long as the amount of motion can be minimized and there is a stable equilibrium position where the pitch motion will cease. In this case, the large pontoon waterplane and closely calculated LCG and LCG constitute the zero pitch equilibrium point and the sphere's buoyancy and added waterplane create the first rotation equilibrium point. The problem

then becomes, and continues to be with all these systems, transverse stability.

Since pitch instability is accepted, an increase in transverse stability with minimum impact on the system could come from increased waterplane at the axis of pitch rotation. By being at the axis of rotation the structure can be smaller than anywhere else and still provide transverse stability as the tower pitches. Thus, the sponsons have been deepened as shown in Figure 5.1.

The next problem is the joining of the large buoyancy spheres to the jacket while the jacket is still installed. The most reasonable thing to do is avoid the mating problem altogether. This is accomplished by using upper leg bottles to catch the jacket during the first rotation in the same manner as the self-floating tower illustrated in Figure 1.4.

5.2 Assumptions

The assumptions required for the pontoon barge system are considerably more refined than those of earlier systems. The major improvement is that it is no longer required to assume that the jacket has been translated from the bottom to floating horizontally at the air/sea interface.

No assumptions need to be made about the spheres since they have been eliminated.

It must be assumed that the pontoon barge can be mated with the jacket on site. This is similar to the clamp-on pontoon mating problem. Blight points out that the equilibrium position of the pontoon after the upper latches are released and the pontoon is riding in the saddle is 0.7° toward the tower. But the tower has a batter of 4.9° which permits some sway in the pontoon as it is released.

It must be assumed that the tower latch points for the pontoon hydraulic latches are still properly dimensioned and structurally sound. The tower is assumed to be sound as well.

It is assumed that the piles have been severed or removed and that any bottom suction can be broken.

Production facilities have, of course, been removed and an accurate weight statement is available. It is assumed that ballast valving and piping is intact and operable and that all ballast tankage is tight, or at least tight enough so that the tanks can still be blown despite air leaks.

Finally, it is assumed that tanks being deballasted to the sea can withstand the pressure differential associated with a rapid pitch up to the surface. Here, a rapid pitch up from the first hold position means a sudden 75 psi increase in internal overpressure in tanks being deballasted with compressed air. Since it is the pontoons that will be

experiencing this, perhaps pumping out the pontoons and venting to the atmsophere should be used since that would mean a maximum external overpressure of 75 psi, which a pontoon barge is particularly well suited to handle due to its configuration.

5.3 Structure

There is only one major structural change required on the tower to enable it to be retracted. To eliminate the spheres the bottom 136 ft of the upper leg must have an increased diameter. The volume of one sphere is 69455 ft^3 and the diameter of the lower section of the existing leg is 14.7 ft. To accommodate the sphere's volume in the leg section's 136 ft length the diameter must be increased to 29.5 ft, which is less than the Ninian South Platform leg diameter, and still within the existing outer ring of pile sleeves.

Minor modifications will be required for jacket ballast piping to minimize maintenance. Vent and drain piping should be run up the tower legs, perhaps inside to be protected, to the top of the tower so no valving will be required at the tank. Another possibility is to replace the valves at the tanks with spool pieces until they are again required. Piping should still run to the top of the tower due to overpressure considerations discussed in Section 5.2.

The other modification is structure added to the barge sponsons. This will require strengthening the sponson supports since the sponson moment on the connections will increase by 30420 ft-tons from about 23,500 ft-tons to 53920 ft-tons. Shear will increase from 1567 tons to 2595 tons.

The structural addition consists of a trapazoidal section joined to the top of each cylindrical sponson (Figure 5.1). The forward end of the addition is in the vicinity of the first rotation waterline. The structure is 109 ft long and 30 ft high. It is configured to provide enough waterplane for a positive GM from preparation through the first rotation. Increased structure will be required to support the flat sides of the sponson extensions.

5.4 Procedure

Retraction is the reverse of installation. The most delicate operation of the entire process is the first one, mating the pontoon barge with the jacket. A fendering system using the Defender shock cell concept should be used to protect the jacket and the barge during the initial positioning of the barge saddles at the base of the tower. Blight has pointed out that the system is particularly vulnerable to transverse waves in this position. The pontoon barge can rotate toward and away from the tower on its saddles but it has little or no capacity to absorb transverse wave energy. Time in this situation must be minimized.

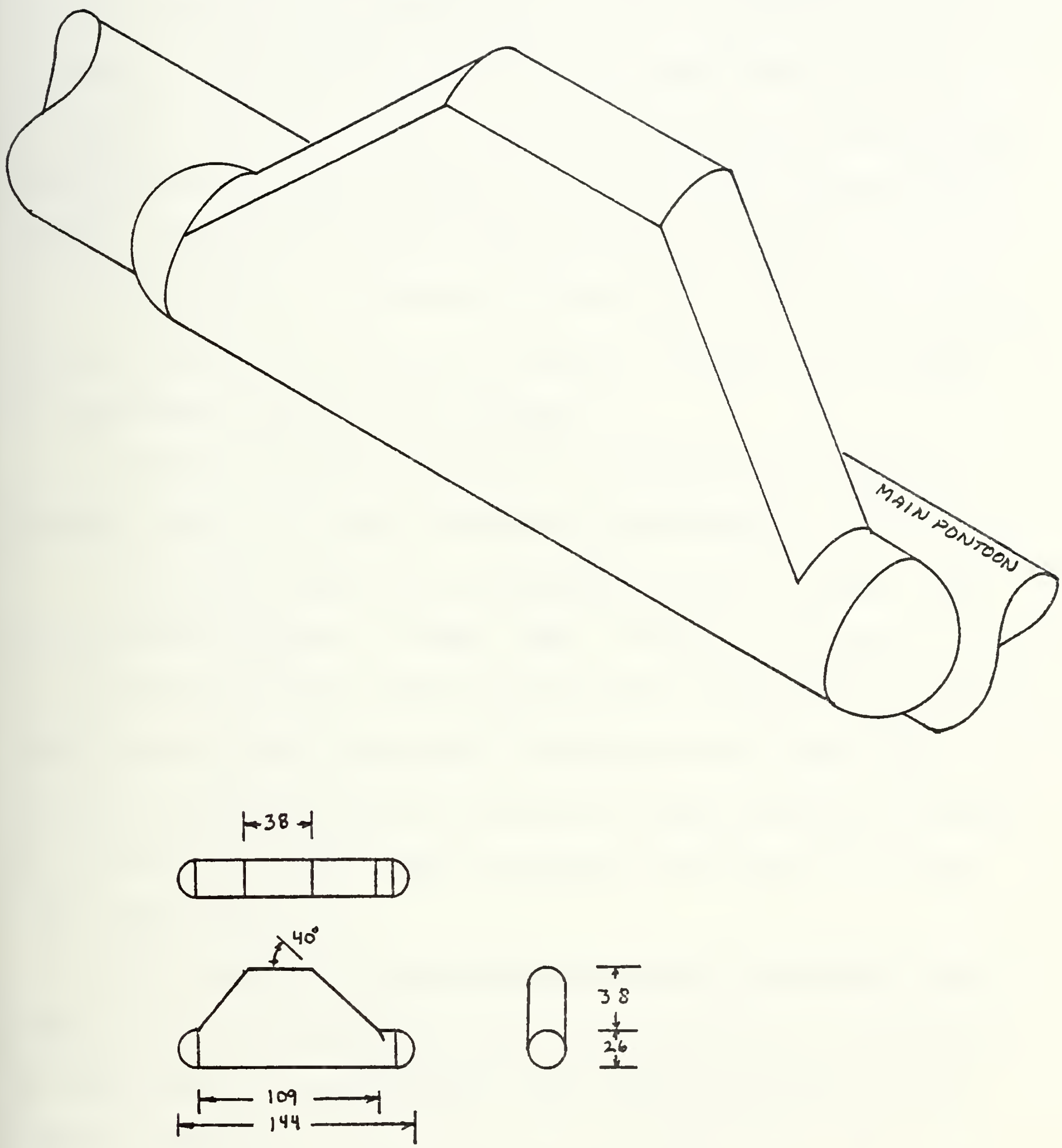


Figure 5.1 Modified Barge Sponson

A factor not present in the original design is the overlap of the sponson extension and the jacket as the barge is mated. Due to the batter of the jacket this will only be about 17 ft, but it will increase the mating difficulties. Flaring the extensions would both ease mating problems and slightly reduce the size of the sponsor extension.

The top of the barge is pulled into the tower and the mating completed by securing hydraulic clamps on the barge to attachment points on the jacket.

After the tower pilings are severed only ground reaction keeps the jacket stable on the bottom.

The next step is to deballast all four jacket legs until ground reaction is near zero. Pumping continues in the large legs (on the side opposite the pontoon) until the jacket rotates in pitch and is resting on two legs only. Careful deballasting of the large legs and the pontoon barge will raise the jacket from the bottom and bring it to the first hold position.

At this point the sponson extension has broken the surface and its waterplane will keep transverse GM positive as deballasting continues and the tower pitches up to the transit position.

During the first rotation of the unmodifed system the maximum negative transverse GM is -23 ft. Therefore,

waterplane to provide 24 ft of BM was sought. The structural addition would be minimized if the waterplane was added near the axis of rotation and as far outboard as possible, Thus making the sponson the logical location. The required waterplane is 120 ft^2 for each side, and if the 26 ft sponson beam is maintained the waterplane length must be 46.3 ft. The extension volume is 70980 ft^3 and displacement is 2028 tons each.

The aft tapered section maintains stability during the actual pitch rotation to the horizontal and the forward rhomboid section operates during the parallel deballasting preceeding the pitching motion. This is only a first cut and the calculations are conservative.

The reduction in BG due to the buoyancy of the sponson extensions has not been considered since the extensions buoyancy is only 4.6 percent of the total buoyancy. This is a conservative assumption.

5.5 Summary

The pontoon barge is the first system discussed which does not require a separate operation to translate the jacket from the seabed to the air/sea interface, and thus it is the first retraction system to have a practical chance of performing the entire retraction operation.

This is also the first real "system" approach to jacket installation. The pontoon barge and jacket are designed to work together and the barge is designed to be re-used. With the simple sponson extensions, modification of the lower parts of two tower legs, and a suitable solution to the grouted pile sleeve problem the system can be used for retraction.

A major advantage of this system is that the large majority of the ballast system piping and components are on the barge and thus can easily be maintained and tested. This greatly lessens the chance of valve, piping, or tank failure.

Maintenance of jacket skid rails is no longer a problem since the jacket is not required to slide. Thus, only crushing blocks on the barge rails may be necessary to cushion mating impact.

There are also weak points which must be watched carefully if this system is to work. In a system using pontoons as with the self-floating tower in Chapter 6, the positions of the longitudinal centers of weight and buoyancy are very critical.

For re-use the jacket must have replacable pile guides or a non-grouted pile system such as that proposed in Chapter 6.

There is still some ballast piping and tankage on the jacket which must be operable for retraction.

The pitching situations will require close analysis and testing to verify stability and structural strength.

Finally, mating the barge with the jacket poses the greatest technical risk. The sponson extensions make calm weather and good rig handling essential.

CHAPTER 6

SELF-FLOATING TOWER

6.1 Basic Concept

A self-floating tower has two legs which are oversized. These legs provide flotation for the tower during transport and installation. While the tower is enroute the flotation legs must provide all the stability and damage control functions of a ship hull or barge, including intact and damage stability. The legs are sufficiently oversized to provide reserve buoyancy and compartmented to provide the required damage stability.

Upon arrival at the installation site the selective flooding procedure outlined in Chapter 1 is initiated. The result is the tower in an upright position on the seabed.

Of the systems investigated this design and the pontoon barge system are the only two systems in which the flotation system is carried with the tower to the ocean floor. This makes the retraction problem easier by an order of magnitude, since a big assumption of the first three systems was that the jacket was floating at the air/sea interface. This system can be designed from scratch for transportation, installation and retraction.

Additionally, cost savings will also result with this plan. Installation is rapid with the exception of a compressed air source for retraction no special handling equipment is

required. In particular, the lift barge is avoided. The cost savings is using constant diameter flotation legs also result in the ability to carry more structure at the top end of the tower. This in turn means less assembly is required on-site and higher platform loads are possible.

Self-floaters for up to 1200 ft water depth have been proposed.[2] The baseline design for this system variation, however, is the Ninian Field South Platform, the background, design, and behavior of which are most ably related by Hancock, White, and Hay,[8] Praught and Clifford,[6] and Praught and Metcalf.[7] Much of the material in this chapter is taken from these sources. The characteristics of the Ninian South Platform are given in Table 1.2.

The goal in developing the self-floating tower is to provide a retrievable system. Given that the piping and valving is maintained and the existing large ballast valve-dynamic installation process is used, retraction is dependent on maintaining transverse stability during the retraction process. A subordinate goal is to minimize impact on the existing design. The simplest means of providing transverse stability during the retraction process is, as with the clamp-on pontoons, by providing waterplane area with a large offset. This can be accomplished by expanding the size of the braces which connect the flotation legs with the upper legs.

6.2 Assumptions

The assumptions required for the self-floating tower are substantially fewer than those required for other systems.

First, of course, the pilings must be severed at or below the mudline. Even if a non-permanent system is developed for securing the piles to the tower, the Geological Survey requirement to leave a clean bottom remains.[1] Retraction of the piles is neither cost effective nor necessary.

As before, it is assumed that the ballast valving and piping are operable and in good condition. It is also assumed that tank strength and integrity have been maintained.

Third, it is assumed that bottom suction on the four large tower leg bases can be broken. This is facilitated by the first retraction step which is a tilting movement rather than a straight vertical lift. Water jets are sometimes used to break bottom suction in the offshore industry.

It is assumed that production facilities have been removed from the tower and that except for the severed pile stubs and grouting in the lower pile guides it is the same weight condition as when it was installed.

6.3 Structure

Structural considerations for retraction are the same as those applicable for installation, and thus minimal design modification is required. A corrosion allowance may

be necessary to maintain required strength margins after ten to twenty years in the ocean environment.

The legs will have extra weight at the base due to the pile stubs and grout, but that should be compensated for structurally by the increased size of the level 1 bracing.

Provision should be made in the pile guide design for refabrication or replacement of the guides. Since they are structures external to the tower legs the pile guides with their pile stubs and grout could be cut off and replaced during the refabrication process. Another possibility is to design the pile guide system so that grouting is not required.

Piles are currently installed by being driven through nearly vertical pile guides or jacket legs. This provides substantial horizontal shear strength at the mudline. However, strength in the vertical direction is provided only by the grouted pile joints. If a retractable system is to be designed the grouting system should be eliminated if possible. One way to accomplish this is shown in Figure 6.1.

Instead of being driven vertically, piles are driven at a large angle from the vertical. The piles are sized and sufficient numbers are installed to provide the required shear and tensile strength at the mudline.

Pile sleeves are located at the base of all four legs, but the sleeves are set at various angles to line up with pile

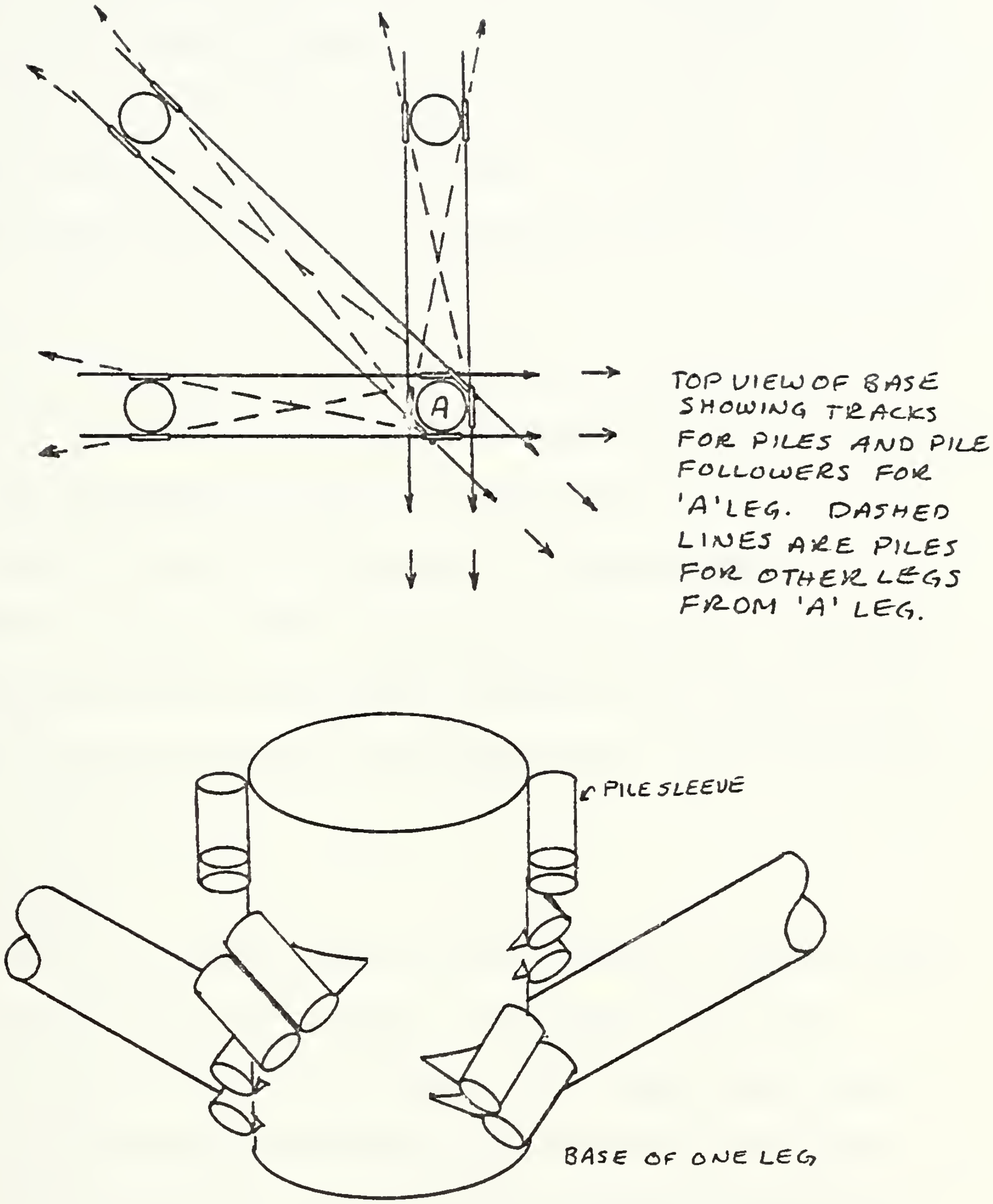


Figure 6.1 Groutless Pile System

follower guides located on the other three legs and on horizontal and diagonal tower braces. The result will be a fan-like spread of piles out from the base of each leg. No piles will be angled inward into the well area. In some areas the follower guides may be mounted on extensions from tower braces.

It is recognized that pile hammers will be less effective while working at an angle and that more piles may be required to develop the strength of a standard pile system. It is felt, however, that the savings in refurbishment time and expense on what would otherwise be a major refurbishment item justifies the investment in design and fabrication. A similar pile system should be considered for any retractable jacket or tower system.

6.4 Procedure

The process of retraction of the modified tower is the reverse of the installation process. All four legs are deballasted to reduce ground reaction. The upper legs are deballasted until an angle of roughly 20° from the vertical is achieved. The flotation legs are then deballasted until the tower rises from the bottom to the fourth hold position shown in Figure 1.4. Deballasting of flotation and upper legs continues until the first hold position is reached. Thus far retraction has been an equilbrium process. This would have

been the case whether the tower was modified or not. A modified tower would require a different deballasting sequence but the process to get from the seabed to the first hold position would be basically the same.

The next deballasting step, from the first hold position to floating horizontally, is the step in which both transverse and longitudinal GM temporarily became negative in the installation of the unmodified tower.

Transverse stability can be improved by adding waterplant offset from the center of gravity. From Figure 1.6 the worst case GM is -18 ft. Using $BM = I/\nabla$, 22,000 tons displacement, and a 123 ft offset, the level 1 braces must each be roughly 24.2 ft in diameter to provide transverse $GM > 0$ during the reversed first rotation.

The effect of this modification on pitch stability is not immediately clear. The center of buoyancy shifts from 200 ft from the base at the first hold position to 250 ft from the base as the jacket pitches down to horizontal. For unflooded level 1 braces this tends to drive the tower to the horizontal position since the center of gravity is in the 247 ft range. However, if the level 1 braces are full, the center of gravity shifts from 247 ft to a minimum of 193 ft from the base. Thus, with proper deballasting the center of gravity can be maintained nearly over the center of buoyancy for the entire first rotation reversal.

In addition, the waterplane of the flotation legs and the level 1 braces provides conservative longitudinal stability of BM > 140 ft.

Obviously, the critical factor here is ballast control. Water may be retained in the level 1 brace tanks as the tower reaches horizontal, to keep the motion slow as the waterplane of the flotation legs very quickly increases. The modified level 1 braces, are large enough to maintain roll stability even if rapid pitching is experienced.

6.5 Summary

The fact that the center of gravity can be maintained over the center of buoyancy through selective ballasting is crucial to the stability of the retraction process. Two 24.2 ft diameter level 1 braces permit this flexibility. In addition, the braces provide substantial waterplane area on large moment arms to ensure transverse as well as longitudinal stability.

It must be kept in mind that a floating tower is sensitive to weight errors of less than 1% and even slight changes in weight can have a drastic effect on LCB and hence longitudinal stability.

The next step in the evolution of the retractable self-floating platform is to develop a math model, particularly of the first rotation, to size the level 1 braces and permit a deballast schedule to be developed, as well as to determine ballasting accuracies required.

CHAPTER 7

CONCLUSION

7.1 Summary of Conclusions

Having examined the five retraction systems, several conclusions can be drawn about each system and about groups of systems.

The side barge system is fraught with technical risks. The cabling, the flotilla and individual size of required side barges, the complicated system dynamics, and the complexities of controll and positioning of a large barge submerging to 180 ft all make the side barge system a questionable choice.

Given a submersible barge, the clamp-on pontoon system is more technically feasible. Mating of the pontoon bases with the jacket, particularly with the pontoons submerged, is a dangerous as well as difficult operation. The jacket-spacific pontoon sizes are also a limitation.

The stable barge is also technically possible, but involves a major effort in a relatively uninvestigated area for the barge superstructures. The non-submerged work platforms make mating a much simpler operation than with the side barge and clamp-on pontoon systems. The fendering system is still jacket specific, as is the shape of the superstructures. Finally, a 200 ft beam plus 30 ft of overhang could impose navigational restrictions.

The fatal flaw of these three systems is their initial assumption of a horizontally floating jacket. As this investigation continued it became apparent that a separate major system would be required.

The pontoon barge and the self-floating tower are the only two systems to begin retraction at the seabed. Both are modified to be made roll-stable during the entire installation and retraction processes and the systems may or may not prove to be pitch stable after modification. Pitch instability from 5° to about 40°, i.e. the first rotation, is acceptable as long as roll stability is maintained.

The self-floating tower requires minimum modification, but it has the most installed system maintance since it provides all its own buoyancy. When installed it is also subject to the largest upsetting moment of any of the systems due to its large leg diameter through the air/sea interface.

The pontoon barge requires minimum modification for transverse stability. The waterplane may be placed in the area of the pitch pivot because the pontoon barge is not a permanent fixture and there is no requirement to minimize drag when vertical. On the self-floating tower this waterplane increase would cause large upsetting moments since it would be just below the installed waterline. Modification of the upper legs of the pontoon barge jacket to eliminate the steadying spheres is not considered difficult.

Both self-floating tower and pontoon barge systems are very sensitive to the longitudinal position of the centers of buoyancy and gravity. This is not a matter of technical risk, but rather it is a matter of careful analysis and calculation.

The mating process required for retracting the pontoon barge jacket remains a matter of moderate technical risk. The rigging situation is simplified by having a fixed tower and a barge that pierces the interface when vertical. Perhaps initial joining could be accomplished above water and those contact points used to pivot the barge into mating at the base. That remains a matter for further investigation.

A last matter of risk for all towers or jackets to be recovered is the pile system. Replacement pile sleeves or some system such as that proposed in Chapter 6 is necessary if a tower or jacket is to be re-used.

Finally, the jacket-specific nature of these designs points toward some sort of jacket classing system based on environmental conditions.

7.2 Recommendations

The benefits to be derived do not warrant the effort required to recover currently installed jackets. No provision has been made for systems critical to recovery and fatigue life vs. oil field life considerations indicate that recovery

is not a worthwhile project. Provisions have not been made to ease refurbishment and in many cases the jacket legs themselves contain grouted piles.

The first three systems discussed in this thesis, the side barge, clamp-on pontoon and stable barge systems, should not be pursued. There is no provision in the jacket to aid recovery, but the biggest problem is the assumption of a horizontally floating jacket. If the submersible barge is modified to mate with a jacket still on the bottom it will evolve into the modified pontoon barge. Also, control of a submersible barge through hoist cables will be difficult.

For any retraction system to work a modified pile system is required. Chipping grouted piles out of pile sleeves is not a cost effective operation. A diagonal pile system such as the one proposed here, or easily replacable pile sleeves must be developed.

Whenever possible, flotation systems should be deballasted by pumping water out rather than by using compressed air to force water out. This will keep overpressure on the outside of the structure and prevent sudden increases in internal pressure if the system suddenly surfaces.

The self-floating tower should be considered, but it is not desirable to invest too much mobile capability in

a fixed platform since that mobility will only be used two or three times during the tower's life. The mobility capability must be serviced and maintained and that means particularly the ballast valving and piping. There remains, of course, the large-drag flotation legs piercing the interface.

Effort should be concentrated on using the pontoon barge concept for installation and retraction. With minor modifications the system is capable of performing the complete installation and retraction processes. The mobile capability is concentrated in the barge, which can be used for a number of jackets. The system ballast capability is also more easily maintained since it too is concentrated in the accessible pontoon barge. Minimal ballast capability and hence maintenance is required on the tower. Minimum modifications to the tower are necessary as well. The major effort should be developing a satisfactory mating system.

The concept of classing jackets for particular environmental conditions should be investigated. Substantial reductions in design duplication would result and the same pontoon barge could be used for a number of jackets.

This thesis has not presented any solutions to the problem of jacket retrieval. It has, however, weeded out some unworkable solutions and brought forth some likely approaches to the problem of retrieving oil production jackets through the air/sea interface.

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APPENDIX A

REGAL SHOCK CELL DATA
(taken from Ref. 14)

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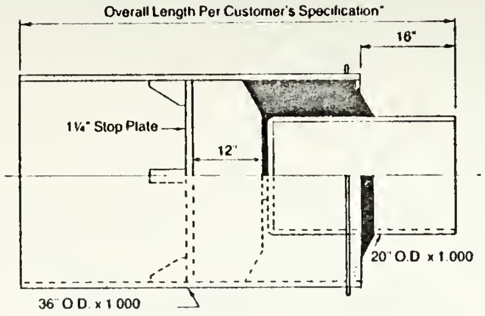

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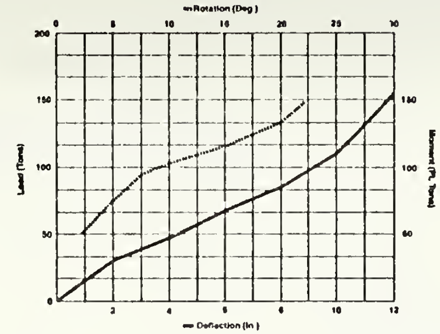
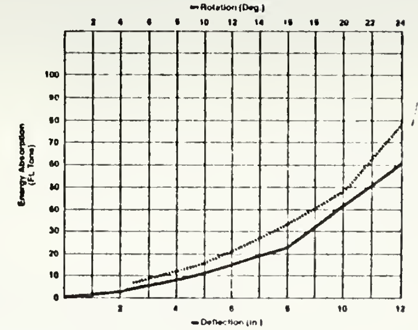
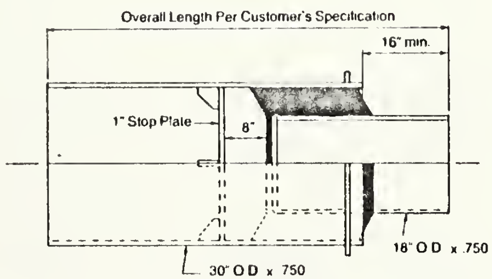


SC-2036
Energy Absorption



SC-1830



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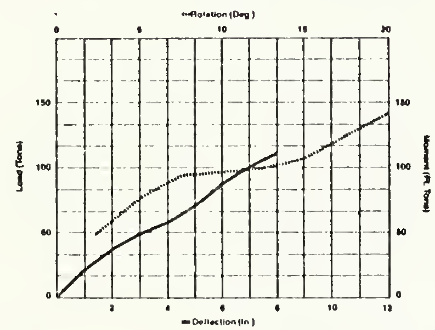

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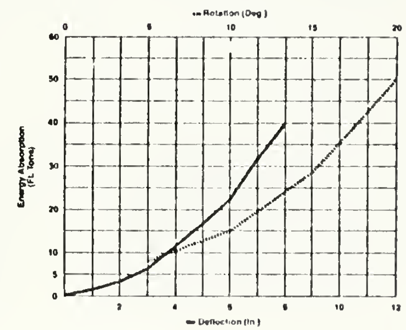
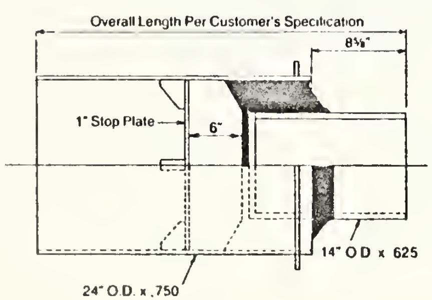
Energy Absorption



SC-1424



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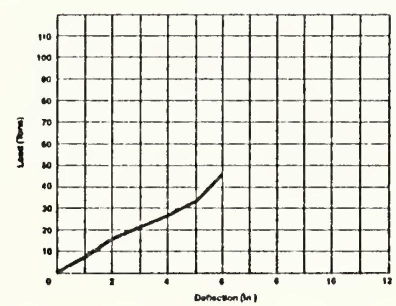
Load Curve



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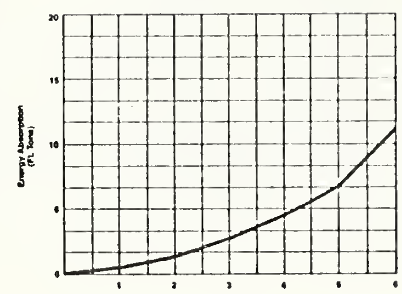
Energy Absorption



APPENDIX B

SMATCO WINCH DATA
(taken from Ref. 15)

84 DISCovery Series
Single Speed Transmission

Characteristics - Line Pull (lbs) and Line Speed (F.P.M.)

FIRST WRAP	450,000 @ stall
	302,000 @ 18
	54,000 @ 92
MID DRUM	259,000 @ stall
	174,000 @ 31
	31,000 @ 160
FULL DRUM	178,000 @ stall
	120,000 @ 45
	22,000 @ 230

100 DISCovery Series
Multi-Speed Transmission

Characteristics - Line Pull (lbs) and Line Speed (F.P.M.)

	Low Gear	High Gear
FIRST WRAP	550,000 @ stall	164,000 @ stall
	440,000 @ 18	131,000 @ 60
	110,000 @ 114	32,900 @ 380
MID DRUM	360,000 @ stall	107,800 @ stall
	290,000 @ 28	66,800 @ 93
	73,000 @ 171	21,800 @ 571
FULL DRUM	270,000 @ stall	60,800 @ stall
	142,000 @ 37	42,500 @ 123
	54,000 @ 232	16,170 @ 774

APPENDIX C

CLAMP-ON PONTOON CALCULATIONS

The following letter symbols are used in these calculations:

ℓ - length of submerged portion of each pair of pontoons

L - length of each pontoon of a pair

R - pontoon radius at each level

r - offset to center of pontoons at each level

X - submergence of the jacket at its center of gravity

To find the center of gravity of the barge-jacket-pontoon system:

$$KG = \frac{KG_{barge}\,W_{barge} + KG_{jacket}\,W_{jacket} + \Sigma\,KG_{pontoon}\,W_{pontoon}}{W_{barge} + W_{jacket} + \Sigma\,W_{pontoon}}$$

KG_{barge} is conservatively half the depth of the 36 ft deep barge.

$$KG_{barge} = 18 \text{ ft}$$

W_{barge} is the barge weight with ballast adjustments for jacket and pontoon submergence.

$$W_{barge} = W_{NB} - W_{JA} + \Sigma W_{PB} - \Sigma W_{P}$$

where

W_{NB} = weight of neutrally buoyant submerged barge

= 95451 tons

W_{JA} = weight of ballast not required due to projection of the jacket above air/sea interface

= 25000 (1-X/146.6) tons

W_{PB} = ballast required due to total submerged pontoon volume

= $2\pi R^2 \ell/35$ tons

W_{PA} = ballast not required due to total pontoon weight

= $(.1)\ 2\pi R^2 L/35$ tons

KG_{jacket} = 112.3 ft

W_{jacket} = 25,000 tons

$KG_{pontoon}$ = barge depth + skid rail height + height of pontoon base above skid rail + half vertical length of the pontoon

= (36 + 3 + BASE HT + L/2) ft

$W_{pontoon}$ = weight of each pair of pontoons

= 10% of pontoon buoyancy

= $(.1)\ 2\pi R^2 L/35$ tons

To find the center of buoyancy of the barge-jacket-pontoon system:

$$KG = \frac{KB_{barge}\ B_{barge} + KB_{jacket}\ B_{jacket} + \Sigma\ KB_{pontoon}\ B_{pontoon}}{B_{barge} + B_{jacket} + \Sigma\ B_{pontoon}}$$

where

KB_{barge} = half depth of barge

= 18 ft

B_{barge} = buoyancy of submerged barge

= 95451 tons

KB_{jacket} = distance from the keel to the center of gravity of the submerged portion of the jacket

= barge depth + skid rail height + half of submergence

= (36 + 3 + X/2)ft

B_{jacket} = buoyant force of submerged portion of the jacket

= 25000 (X/146.6) tons

$KB_{pontoon}$ = barge depth + skid rail height + height of pontoon base above skid rail + half vertical length of the submerged portion of the pontoon

= $(36 + 3 + \text{BASE HT} + \ell/2)$ ft

$B_{pontoon}$ = buoyant force of submerged portion of each pontoon pair

= $2\pi R^2 \ell/35$ tons

To find the contribution of GM due to waterplane area:

$$BM = I/\nabla$$

$$= \frac{\Sigma\ 2\pi R^2 (r+R)^2}{\nabla_B + \nabla_J + \Sigma\nabla_P}$$

where

I = second moment of area of pontoon waterplane around barge centerline (ignoring self-moments)

= $\Sigma\ 2\pi R^2 (r+R)^2\ ft^4$

∇_B = volume of submerged barge

= 500*160*36

= 3,340,800 ft^3

∇_J = volume of submerged portion of the jacket

= $25000 * 35 * X/146.6 \text{ ft}^3$

∇_P = volume of submerged portion of pontoons at each level

= $2\pi R^2 \ell$

APPENDIX D

HP-41C CALCULATOR PROGRAM FOR CLAMP-ON PONTOONS

Program

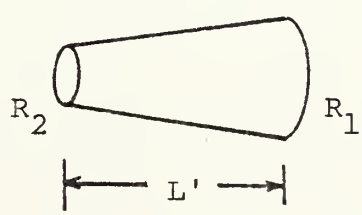
```
01*LBL "GM"
02 187
03 STO 31
04 161.95
05 STO 32
06 13.42
07 STO 33
08 118.3
09 STO 34
10 129.5
11 STO 11
12 117
13 STO 12
14 105.7
15 STO 13
16 95.4
17 STO 14
18 "AUTO? Y1, N=0"
19 PROMPT
20 STO 05
21 CF 01
22 CF 02
23 0
24 "MAN OFFSET?,1"
25 PROMPT
26 X=0?
27 SF 01
28 0
29 STO 15
30 STO 16
31 STO 17
32 STO 18
33 STO 50
34 STO 51
35*LBL A
36 "LEVEL? O.END"
37 PROMPT
38 X=0?
39 GTO 04
40 STO 10
41 10
42 +
43 "RADIUS?"
44 PROMPT
45 STO 00
46 RCL IND Y
47 FS? 01
48 GTO 09
49 "OFFSET +?"
50 PROMPT
51*LBL 09
52 +
53 X²
54 26
55 RCL 10
56 +
57 X<>Y
58 STO IND Y
59 14
60 RCL 10
61 +
62 RCL 00
63 X²
64 STO IND Y
65 18
66 RCL 10
67 +
68 "BASE HT?"
69 PROMPT
70 STO IND Y
71 22
72 RCL 10
73 +
74 "TOP HT?"
75 PROMPT
76 STO IND Y
77 GTO A
78*LBL 04
79 000.1412
80 STO 01
81*LBL B
82 0
83 STO 06
84 STO 07
85 STO 08
86 STO 36
87 4
88 STO 10
89 RCL 05
90 X=0?
91 GTO 05
92 FS? 55
93 ADV
94 RCL 01
95 INT
96 STO 02
97 "X="
98 ARCL X
99 AVIEW
100 GTO 06
101*LBL 05
102 "X-?"
103 PROMPT
104 STO 02
105*LBL 06
106 146.6
107 /
108 STO 03
109 25000
110 *
111 95451
112 +
113 STO 35
114*LBL 03
115 0
116 STO 09
117 14
```

```
RCL 10
+
RCL IND X
X=0?
GTO 09
30
RCL 10
+
RCL IND X
RCL 03
*
STO 40
22
RCL 10
+
RCL IND X
STO 04
X<>Y
RDN
X>Y?
X<>Y
18
RCL 10
+
RCL IND X
ST- 04
STO 41
X<>Y
RDN
-
X>0?
STO 09
14
RCL 10
+
RCL IND X
2
*
PI
*
ST* 04
STO 42
RCL 09
RCL 40
RCL 41
-
X>Y?
GTO 07
X<0?
GTO 07
RCL 42
26
RCL 10
+
RCL IND X
X<>Y
RDN
X<>Y
*
ST+ 36
*LBL 07
RCL 42
RCL 09
*
35
/
ST+ 08
18
RCL 10
+
RCL 09
2
/
39
+
RCL IND Y
+
X<>Y
RDN
*
ST+ 07
RCL 04
.1
*
35
/
ST+ 06
*LBL 08
DSE 10
GTO 03
95451
18
*
RCL 02
2
/
39
+
25000
*
RCL 03
*
+
RCL 07
+
RCL 35
RCL 08
+
STO 54
/
STO 37
"KB="
ARCL X
AVIEW
FC? 55
STOP
RCL 36
RCL 54
35
*
/
STO 38
"BM="
ARCL X
AVIEW
FC? 55
STOP
+
RCL 35
25000
-
RCL 08
+
RCL 06
.1
*
-
18
*
25000
112.3
*
+
RCL 09
```

```
2
/
39
+
RCL 41
+
RCL 06
*
.1
*
+
RCL 54
/
STO 39
"KG="
ARCL X
AVIEW
FC? 55
STOP
-
"GM="
ARCL X
AVIEW
FC? 55
STOP
RCL 05
X=0?
GTO B
ISG 01
GTO B
BEEP
GTO 10
*LBL E
SF 02
*LBL D
STO 43
X²
X<>Y
STO 44
X²
+
RCL 43
RCL 44
*
+
STO 47
X<>Y
STO 48
*
PI
*
3
/
"VOL="
ARCL X
AVIEW
STO 45
FS? 02
CHS
ST+ 50
RCL 44
X²
3
*
RCL 43
X²
+
RCL 44
RCL 43
*
2
*
+
RCL 47
/
4
/
RCL 48
*
"VCB="
ARCL X
AVIEW
STO 46
"CONE BASE,HT?"
PROMPT
+
*
ST+ 51
RCL 51
RCL 50
/
"CG="
ARCL X
AVIEW
RCL 50
"EQUIV RADIUS"
PROMPT
X²
/
PI
/
2
/
+
"TOP HT="
ARCL X
AVIEW
LASTX
2
*
-
CF 02
"BASE HT="
ARCL X
AVIEW
*LBL 10
.END.
```

Registers

00 CURRENT OFFSET
01 DEPTH INCREMENT
02 SUBMERGENCE X
03 X/146.6
04 CURRENT $2\pi R^2 L$
05 AUTO 1; MANUAL 0
06 $\Sigma\ 2\pi R^2 L/35$
07 $\Sigma(39 + \text{BASE HT} + \ell/2)2\pi R^2\ell/35$
08 $\Sigma\ 2\pi R^2\ell/35$
09 CURRENT ℓ
10 LEVEL DECREMENT
11-14 OFFSETS
13-14 SAME AS 11-12 OFFSETS FOR 2 SETS OF STACKED PONTOONS
15-18 RADIUS R^2
19-22 BASE HEIGHT
23-26 TOP HEIGHT
27-30 $(R+r)^2$
31-34 STATION HEIGHTS
33-34 SAME AS 31-32 FOR 2 SETS OF STACKED PONTOONS
35 95451 + 25000X/146.6
36 $\Sigma\ 2\pi R^2(R+r)^2$
37 KB
38 BM
39 KG
40 CURRENT HEIGHT * X/146.6
41 CURRENT BASE HEIGHT
42 CURRENT $2\pi R^2$
43 R_1
44 R_2
45 W
46 VCG
47 $(R_1{}^2+R_1R_2+R_2{}^2)$
48 L'
50 ΣW
51 ΣM
54 $95451 + 25000X/146.6 + \Sigma\ 2\pi R^2\ell/35$



Thesis 198849
F4723 Fiske
c.1 The use of bouyancy
to lift heavy objects
from the sea.